STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

CALIFORNIA'S EXPERIENCE WITH THE RECORD SAMPLING PROGRAM

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In April, 1960, the Bureau of Public Roads issued Instructional Memorandum 20-5-60. This has been supplemented by two succeeding memorandums, 20-5-60(1), January, 1961, and 20-6.2, January, 1962. These memorandums make it mandatory for the states to produce evidence that contract work conforms to the plans and specifications on all Federal supported projects. I am sure that everyone is familiar with the circumstances which prompted the U.S.B.P.R. to issue the detailed requirements relating to the inspection, testing and certification of Federal and Federal-Aid highway projects. Other than the Federal-Aid acts providing funds for the nation's highways, it is probably safe to say that few pieces of paper have had more effect upon the lives and actions of highway engineers in the fifty states.

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The first memorandums left something to be desired in the way of clarity. The following is quoted from a paper presented to WASHO in 1961, entitled, "The Record Sampling Program," by L. W. Little, Materials and Testing Engineer for the State of Nevada:

> "Issuance of these instructional memoranda, particularly the latest one, has presented so many uncertainities that it is difficult to see how uniformity of procedure can be set up nationally or regionally. A maze of possibilities is set forth as to who is to select the sample points, who is to take the samples, and who is to supervise whom in taking and testing them. Some of the definitions are obscure, and while it is required that thickness measurements be taken, no tolerances have been set up by the Bureau of Public Roads nor has recommendation been made as to how to proceed in establishing tolerances."

Mr. Little's comment is supported by the evidence that the intent has been variously interpreted not only by the states but also by Bureau engineers in the different regions.

The first memorandum seemed to place the greatest emphasis on a series of final samples to indicate the quality and the thickness of layers in the finished pavement structure. It was stipulated that these samples were to be taken by U.S. Bureau of Public Roads engineers or by central laboratory personnel of each state. The latest directive (20-6.2, January, 1962) stresses the need for an additional program called "progress sampling and testing" which, in effect, is an independent direct check on the job sampling and testing done by the resident engineer or project engineer. The language of the new directive is much clearer than the previous ones and is quite specific as to the requirements except that there are no guides on acceptable tolerances. This latest memorandum relaxes none of the previous requirements but does clarify the meaning of the term "central" laboratory. It is now clear that the district laboratories may be included under this term. The memorandum also clearly defines three general classes of samples:

1. Job samples and testing.
2. Progress samples and testing.
3. Final samples and testing.

In California, our efforts to comply with the first directive (April, 1960) have required an expenditure exceeding $350,000.00 per year. This work was confined almost entirely to the final sampling and testing phase. The program of final sampling or record sampling in California has been termed the "Engineering Audit" in recognition of the similarity to the increasing infestation of auditors in all branches of public works, especially highways. It is becoming increasingly difficult to make even an engineering decision without considering the possibility or probability of having to explain and to account to some auditor, attorney or perhaps an investigator from a congressional or legislative committee. In California, the Division of Highways is subject to the attentions of five separate auditing agencies, none of whom have any direct responsibility for the quality, cost or efficiency of highway design, construction or maintenance activities.

Because of the lack of specific instructions in the first Bureau directive, it was necessary for California, as in the case of the other states, to reach an immediate agreement on the number of samples to be taken and the amount of testing required to indicate whether the completed work was in substantial conformance to the plans and specifications. California is fortunate in having a Division Engineer of the Bureau of Public Roads who thoroughly understands the problems involved, and there has been no difficulty in arriving at a workable agreement. In the absence of any guides, it was decided that the Engineering Audit (or Final Sampling) should be based on one sample per lane mile of completed highway plus one sample for each four miles of shoulder section. Additional samples are taken in the vicinity of any test hole showing inadequate thickness of layer. All of these samples are taken by three to five crews operating under the direction of Headquarters Laboratory in Sacramento. One crew is stationed in Los Angeles and covers the southern California districts. The total number of individuals whose time is largely taken up with this activity is around 35 which includes field crews, laboratory personnel, typists and engineers of the Headquarters Construction Department who handle the reconciliation between the results of the audit test and the job records. The numerous and ubiquitous auditing groups were mentioned above and if auditors confined their attention solely to the accounts, records of expenditures, et cetera, it would be unnecessary to mention their activities in connection with the sampling and testing program. However, California's experience has shown that auditing groups are not inhibited by a lack of engineering knowledge and do not necessarily limit their criticism to matters of bookkeeping.

As all highway engineers are aware, there have been widely publicized reports of pavements found in certain states that were less than the specified thickness. By way of background, it may be explained that in the process of estimating the tonnage required to produce a certain thickness of asphaltic pavement, the specification writer must make certain assumptions as to the specific gravity of the aggregate which the contractor may elect to use and the compaction which will be achieved. Usually, the quantities set up in the contract are based on an assumed normal specific gravity for the aggregates and upon a certain compacted density as indicated by preliminary laboratory specimens. In California, the density is predicated upon results achieved in the Kneading Compactor which, in turn, is adjusted to produce a density comparable to the average pavement after one year's traffic. However, the contractor is required to obtain only 95 percent of the density achieved in the laboratory. Strictly speaking, this means that the thickness of a newly laid asphaltic pavement should properly be a little more than the thickness shown on the plans in order to allow for the further compaction which invariably takes place with time and traffic. As a result, it has become common practice throughout the years (and apparently in most states) for the engineer to control the spread in accordance with the tonnage provided in the contract. This means that the asphaltic pavement layers, when sampled shortly after construction, tend to average a little thicker than called for in the plans. This was always felt to be a good safety factor and insures that even with the normal variations which occur with all spreading devices, the thickness of pavement would everywhere be equal to or slightly above the minimum specified. As pay quantities for asphaltic pavements are generally based on the tonnage of material, the average engineer felt that this practice was beyond question and that the state was getting what it paid for. We find, however, that this approach does not always appear reasonable to the auditors and on several occasions the question has been raised as to why the state should pay for any greater thickness than was called for on the plans. On the other hand, the Bureau of Public Roads may refuse to participate if the pavement is below the specified thickness. This means that the construction engineer and the contractor are being forced to work within much narrower tolerances. The highway engineer is being driven to revise specifications in an attempt to spell out in greater detail the permissible tolerances and variations which have always been recognized as a matter of common sense and engineering judgment.

This question of tolerances has many ramifications and one must draw a distinction between tolerances which would be suitable for specification use and the type of tolerances appropriate for interpreting the results of a record sampling program. Tolerances for inclusion in contract specifications are difficult to write as the effect is generally to simply shift the specified limits to a broader band represented by the extremes of the tolerances stipulated. There is, however, a definite and increasingly acute need for workable and practical tolerances in the plans and specifications without, at the same time, relaxing the essential controls. Tolerances to be used in judging the results of final sampling or engineering audit are a somewhat different matter and should be based upon a different principle. In other words, there is only a certain chance or probability that random samples of a small area will faithfully represent the project as a whole. Therefore, it is only reasonable that the results of the final sampling program be interpreted in terms of a scale of values which recognizes the probability of some deviation from the plans. California has established such a table of tolerances for the thickness of the various structural layers (See Table I). These values have appeared to be reasonable and workable. Charts, Fig. 1 and 2, are typical sections for a two lane pavement in California. Figures 3 to 16 illustrate the variation in pavement thickness which has been found over the past two years on state highway work in California. Figures 17 and 18 show the variation in R-value for the aggregate subbase and base materials. Figures 19 and 20 illustrate the range in Sand Equivalent values.

All of these charts portray the range of variation which is typical of the work under way at the time the engineering audit was initiated and also show the range for 1961 which indicates a general tightening up of construction control.

The variations in R-value for the granular bases indicate a very close control and a rather surprising uniformity. As a basis for comparison by those who may not be familiar with the R-value measurement, Charts, Fig. 21 and 22, are included to show the range in compressive strength of portland cement concrete based on 5-in. diameter cores taken from the pavements. This concrete was mixed in modern equipment and all steps subjected to close inspection. The range of variation in strength may be a little surprising to those who assume that concrete is a highly uniform material. Figures 23 and 24 show the range for 6 by 12 in. cylinders of structural concrete as placed in bridges. I am not here implying that the concrete represented by these compression test values is deficient or likely to give trouble. It may be, however, that data such as these should be kept in mind when judging the variations brought to light by other tests on materials.

Tolerances for deviations in gradation of aggregates are difficult to apply and more difficult to justify. The pavement thickness value is a definite figure, but grading specifications, as written, already include tolerances and therefore it is hardly reasonable to add tolerances on to tolerances.

In considering whether aggregate gradations of samples taken from the road comply with specifications, one is almost invariably confronted with the question of degradation. Unfortunately, most standard tests, such as the L.A. Rattler, do not forecast the amount of degradation which may be caused by handling, spreading and compaction of aggregates. Many cases are known where aggregates which meet the L.A. Rattler requirements when sampled in the pit or production plant will break down and degrade in the process of handling and compacting on the road. Final samples taken from the road frequently show a marked increase in fines and while it is customary for engineers and contractors to claim that the specifications apply only at the plant or in the vehicle at the point of delivery, it is a hard matter to convince an auditor, an investigator or even ourselves that it really doesn't matter what gets on the road so long as the material met the specifications "back down the line somewhere." California has developed a degradation test which will be known as the Durability Test for Aggregates. Test procedures are established for both fine and coarse aggregates. The Durability Test for coarse aggregate is made by using the equipment for the Cleanness Test (Tyler sieve shaker and a stainless steel vessel) and the fine aggregate is tested in the Sand Equivalent apparatus using the motor driven shaker. The procedure is quite simple and takes only a short time. Briefly, clean washed samples of the aggregates are placed in the container and vigorously shaken or agitated for ten minutes, at the end of which time an aliquot sample of the wash water is mixed with the Sand Equivalent solution and the height of column after twenty minutes is noted. Values for either coarse or fine may range from 80 for such hard materials as quartz down to 5 or less on clay bound sandstones and shales. A passing value of 35 appears to be appropriate and this Durability Test will reject a large percentage of those aggregates which have been found to break down on the road even though meeting the L.A. Rattler Test requirements. Figure 25 shows the relationship between the L.A. Rattler and the new Durability Test. The ordinate shows values for both coarse and fine aggregate, while the abscissa values show the L.A. Rattler loss at 500 revolutions for the coarse materials. It will be noted that the very soft materials show up adversely in both tests, but there are certain samples meeting the present L.A. Rattler requirements which break down when shaken in water for only ten minutes. It will be observed that there is little or no correlation between the L.A. Rattler and the Durability Test for the majority of materials shown on Fig. 25. This test is only a recent development and data are lacking to prove that all materials meeting the Durability Test requirements will pass through the handling and placing process and still meeting grading specifications when sampled from the road. Nevertheless, it is virtually certain that the use of the Durability Test will materially reduce the cases where the final record samples are outside the specifications.

For the information of those who are not familiar with the Sand Equivalent Test, it may be emphasized that the sort of breakdown developed in the new Durability Test differs from the results of the L.A. Rattler. The chief difference is that the Durability Test does not evaluate the amount of sand or coarse materials that are produced but instead reflects the amount of very fine potentially lubricating fractions in the clay sizes to which the aggregate may degrade.

In preparing this paper, a questionnaire was sent to the Materials Engineers of the fourteen states composing the Western Region of the AASHO and to twelve states farther east. There is attached a copy of the questionnaire and a tabulation of answers, Table II, from those states replying. The frequency of sampling ranges from one every thousand feet to one sample for each two lane miles. All states replying indicated that the sampling is done by laboratory personnel or by the Bureau of Public Roads engineers. The ideas about thickness tolerances vary rather widely. Idaho, Washington and

California apparently have the greatest detail on tolerances applied to final samples. There is reasonable agreement among the states as to the laboratory tests performed on the samples taken from the road. Fourteen states indicate that job sampling is being checked by central laboratory personnel. Five states have not yet taken this step. Thirteen states indicate that there is evidence of an improvement in the control of the work. Five states have answered, "No." While it is evident that there are differences in the methods of handling the program in the several states, on the whole the amount of testing is not too dissimilar. However, only few states gave figures to show how much this program is costing. California estimates some $350,000.00 per year. Illinois reports about the same amount. Other states such as Georgia, Idaho, Kansas, Louisiana, Oregon and Washington report expenditures ranging from $25,000.00 to $250,000.00 per year, which sums are quite comparable considering the size of the respective highway budgets. Other states are uncertain about the costs, while one, Colorado, states that their costs have not been increased as they were carrying on the same sort of sampling and checking previous to the Bureau directive. New Mexico appears to be doing the most extensive job of sampling as they report about three times as many specimens per mile of pavement as any other state.

It is difficult to assess the value of this program. I am sure that all engineers have long been convinced that the process of sampling and testing materials is worthwhile, in fact, absolutely essential. However, to be of greatest and most direct value, sampling and testing should be performed before the materials are finally in place. Of the three types of samples now required by the Bureau, the first group, or job control samples, represents little or no change from the practice which has been followed more or less thoroughly in all states. The second type of samples, now called progress samples, will mean additional work for nearly all. The third class, or so-called record samples and tests, is taken from the completed work and for the most part will be too late to have any effect on the specific project from the standpoint of effectiveness in maintaining or improving the quality of state highway work. The first two classes of samples will be most effective. The final or record samples are more or less a post-mortem type of operation and can be beneficial only indirectly.

Several morals or conclusions may be drawn from a consideration of this development. First, it brings home the fact that all are affected by the actions of a few. In this case, a few examples of irregularities on a few projects in two or three states have led to an expenditure for inspection, sampling, testing and reporting which must be costing the public somewhere in the range of three or four million dollars annually, and when the progress sampling is placed in effect the total expenditure may well exceed seven million dollars. Whether the quality of the work will be improved, the life of pavements and structures increased and maintenance cost reduced sufficiently to justify this expenditure can only be a matter of opinion at the present time. Virtually all states have reported an improvement in the quality of the work.

Figures 2 to 20 illustrate some of the improvements noted in California. While this improvement is small it is definitely evident both in the measurements of pavement thickness and in compliance with quality requirements such as the R-value, Sand Equivalent, aggregate gradation, et cetera.

Final Comment

It has been said that we are prone to judge ourselves by our intentions but we judge others by their actions. Applying this concept to the highway program, all of the preliminary work, plans, designs and writing of specifications may be thought of as an expression of our "intentions". However, investigative committees and the public will inevitably judge us on what we do - not on what we intended. In recent years, the planning function in virtually all highway departments has received the major emphasis with the result that top management has had less time to think about the actual execution or "doing" of the work. One consequence of declining emphasis on materials and construction details is the widespread practice where resident engineers or project engineers assign the work of testing and materials control to the youngest, least experienced and often lowest paid man on the job. While undoubtedly the majority of these men are competent and conscientious, such an over-all atmosphere does not tend to stress the importance of job control, sampling, testing and the need for compliance with specifications.

One point which perhaps needs to be emphasized and constantly reiterated is that a contract to build a section of state highway is a legal document and once the plans have been completed, the specifications written, and the contract awarded, engineering considerations must, in effect, become subordinate to strict legal interpretation and there is inevitably a close tie between the legal determination of fact and the recognized processes of accounting. Over 90 percent of all the money spent for highway construction is actually spent for materials. Virtually all pay items for highway contracts are stated in terms of materials in place and the specification clauses covering payment usually stipulate that the price paid includes all hauling, placing, shaping and consolidating of the material on the road. It is not too surprising if accountants and other non-engineering investigators should assume that the quality requirements in the specifications were meant to apply to the final product for which payment is made. Few engineers would contend that low strengths on cores cut from a concrete pavement are a matter of no consequence so long as cylinders fabricated at the plant tested O.K. A common explanation for failure of aggregates sampled from the roadbed to meet grading specifications is that the materials have degraded during handling and placing. However, this explanation or excuse inevitably leads to some uncomfortable conclusions. First, we would have to argue that fine material or clay in excess of the specifications is not detrimental. However, most of us already have our specification limits on the minus 200 set as high as we believe to be safe. Attempts to declare the specification limits inapplicable to the final material in place gives us no protection against careless handling of aggregates or the incorporation of subgrade soil, mud from the roadside or other contamination. We pay contractors for materials on the road or in a structure - not at the plant or in a truck.

A conscientious engineer is properly concerned and restive over any requirement that increases the amounts appearing on the books as engineering costs. However, it is difficult to develop convincing arguments against the continuance of such a program as that outlined by the Bureau under the heading of record sampling and testing.

August 10, 1960

CALIFORNIA DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

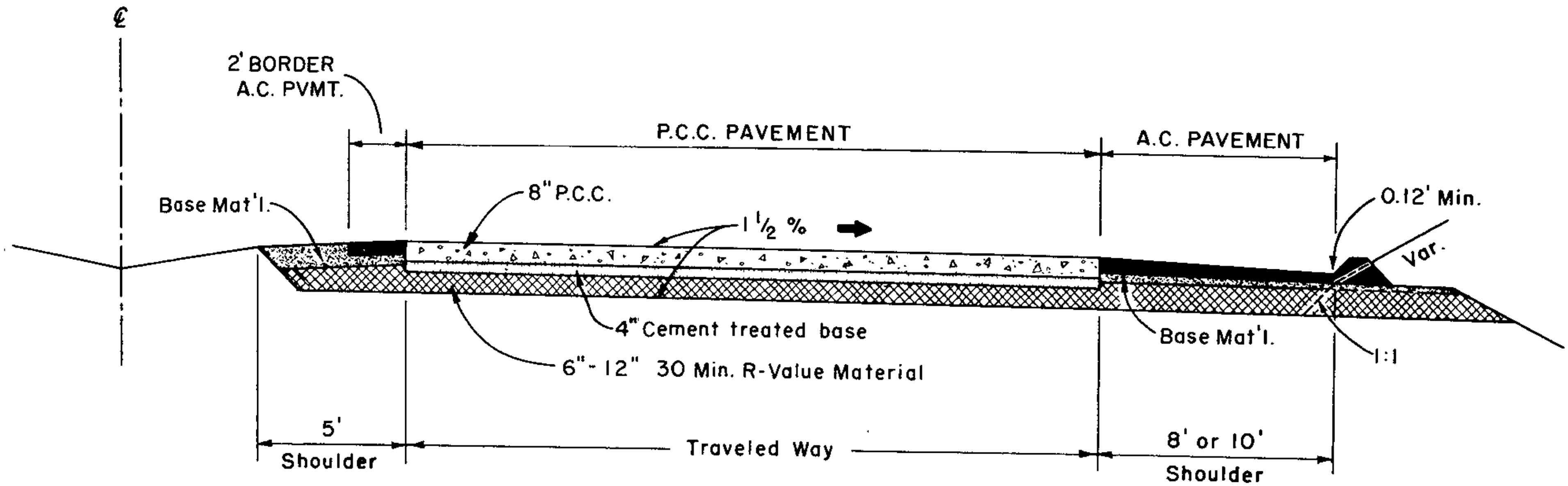
Engineering Audit of Materials and Construction

Acceptable Variations in Random Samples
for
Thickness of Base and Pavement Layers

	80% of all test holes to be within the following tolerances		None to Exceed
	Minus	Plus	Minus
Aggregate Subbase	-0.10'	-	-0.20'
Road Mix CTB Lime Treated Base Bituminous Treated Base	-0.08'	+0.12'	-0.15'
Aggregate Base	-0.05'	+0.08'	-0.10'
Plant Mixed CTB	-0.04'	+0.06'	-0.08'
Road Mixed Bituminous Surface	-0.03'	+0.05'	-0.06'
Asphaltic Concrete Pavement	-0.02'	+0.04'	-0.04'
Portland Cement Concrete Pavement	-0.01'	+0.03'	-0.02'

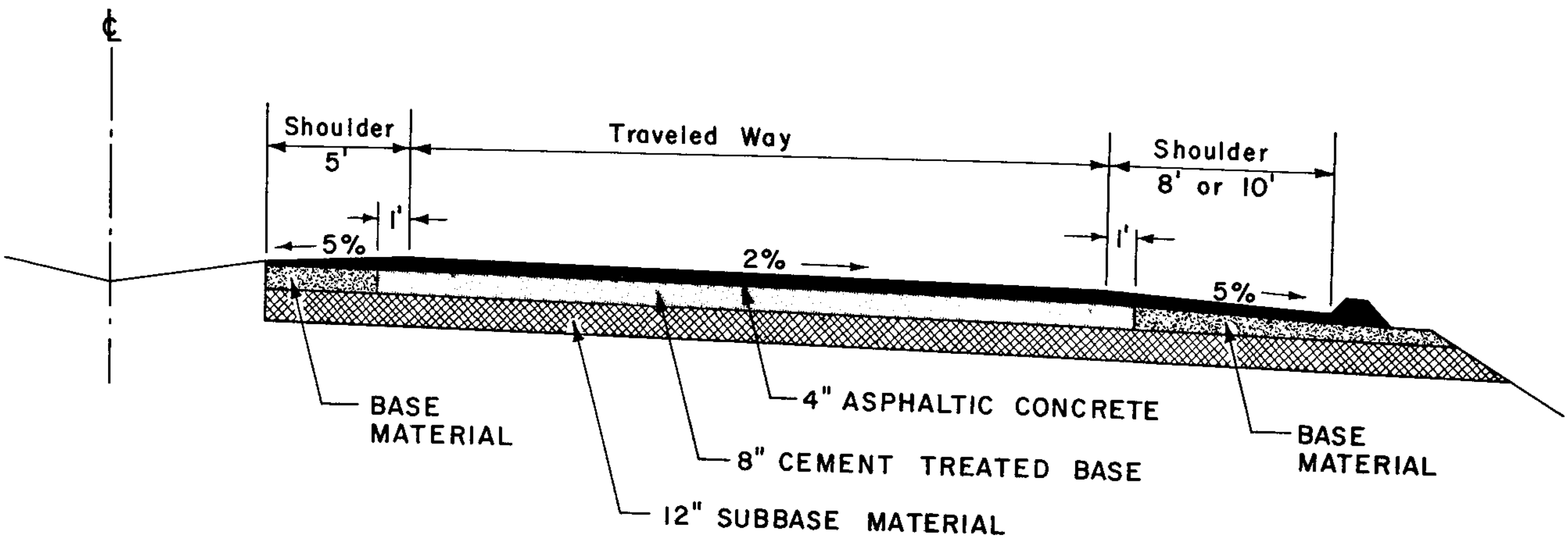
Note: To be used only for judging adequacy of pavement thickness as indicated by samples cut or cored at random locations.

Table I



TYPICAL SECTION — PCC PAVEMENT

Figure 1



TYPICAL SECTION — A C PAVEMENT

Figure 2

ENGINEERING AUDIT OF CONSTRUCTION

GRAPHICAL ILLUSTRATION OF VARIATION IN THICKNESS

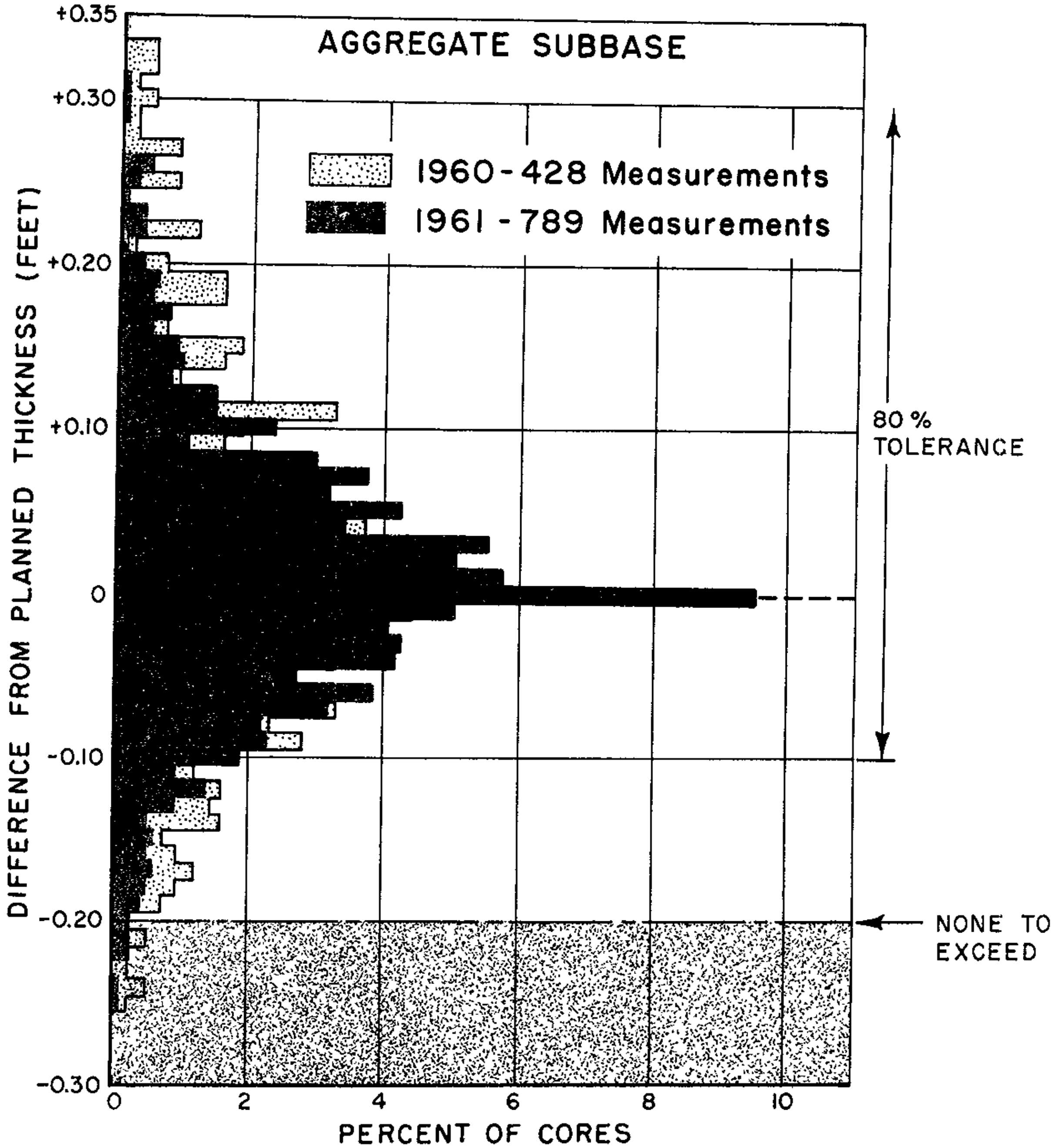


Figure 3

OGIVE CURVE FOR THICKNESS MEASUREMENTS OF AGGREGATE SUBBASE

1960 and 1961 AUDIT SAMPLING PROGRAM

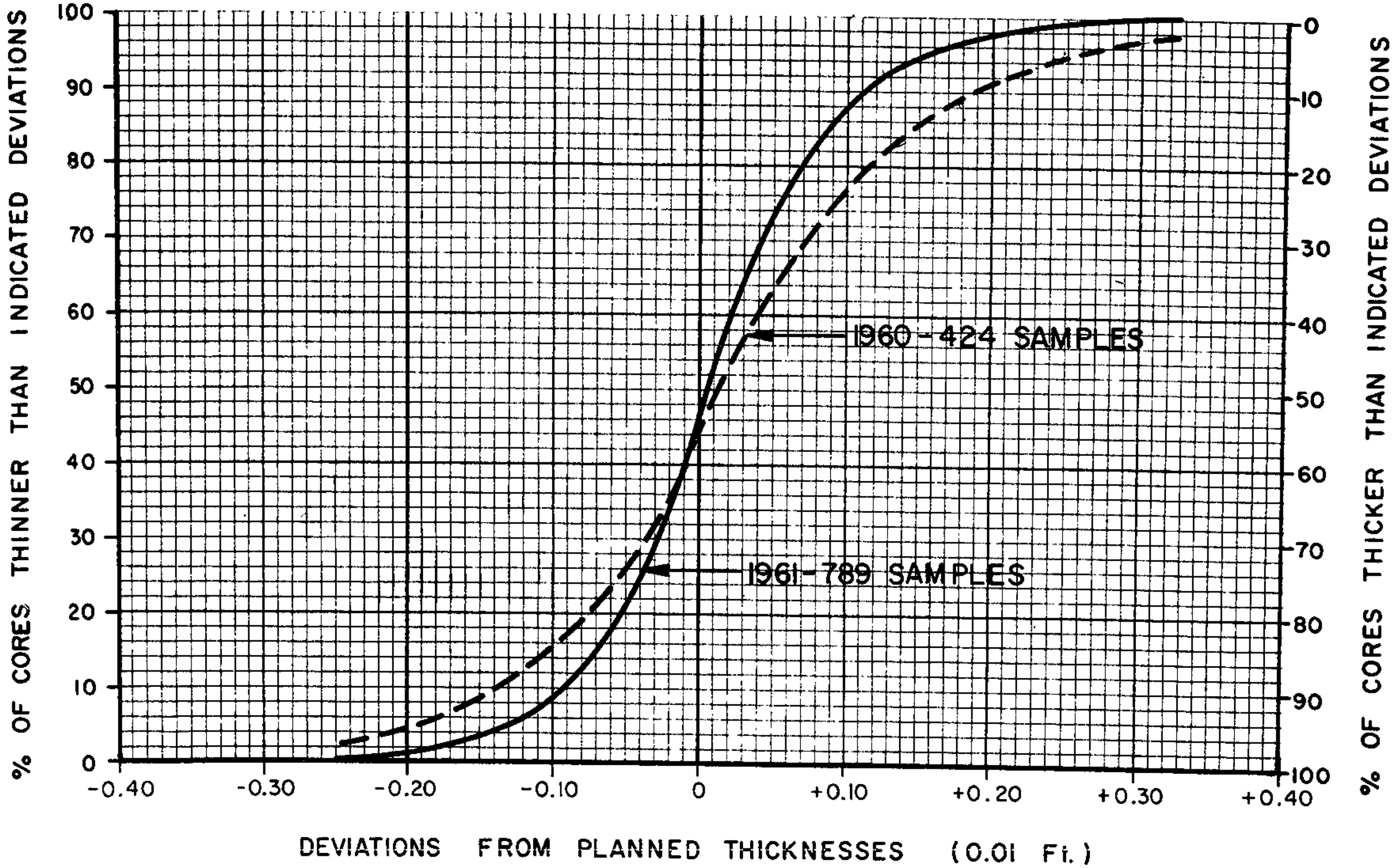


Figure 4

ENGINEERING AUDIT OF CONSTRUCTION

GRAPHICAL ILLUSTRATION OF VARIATION IN THICKNESS

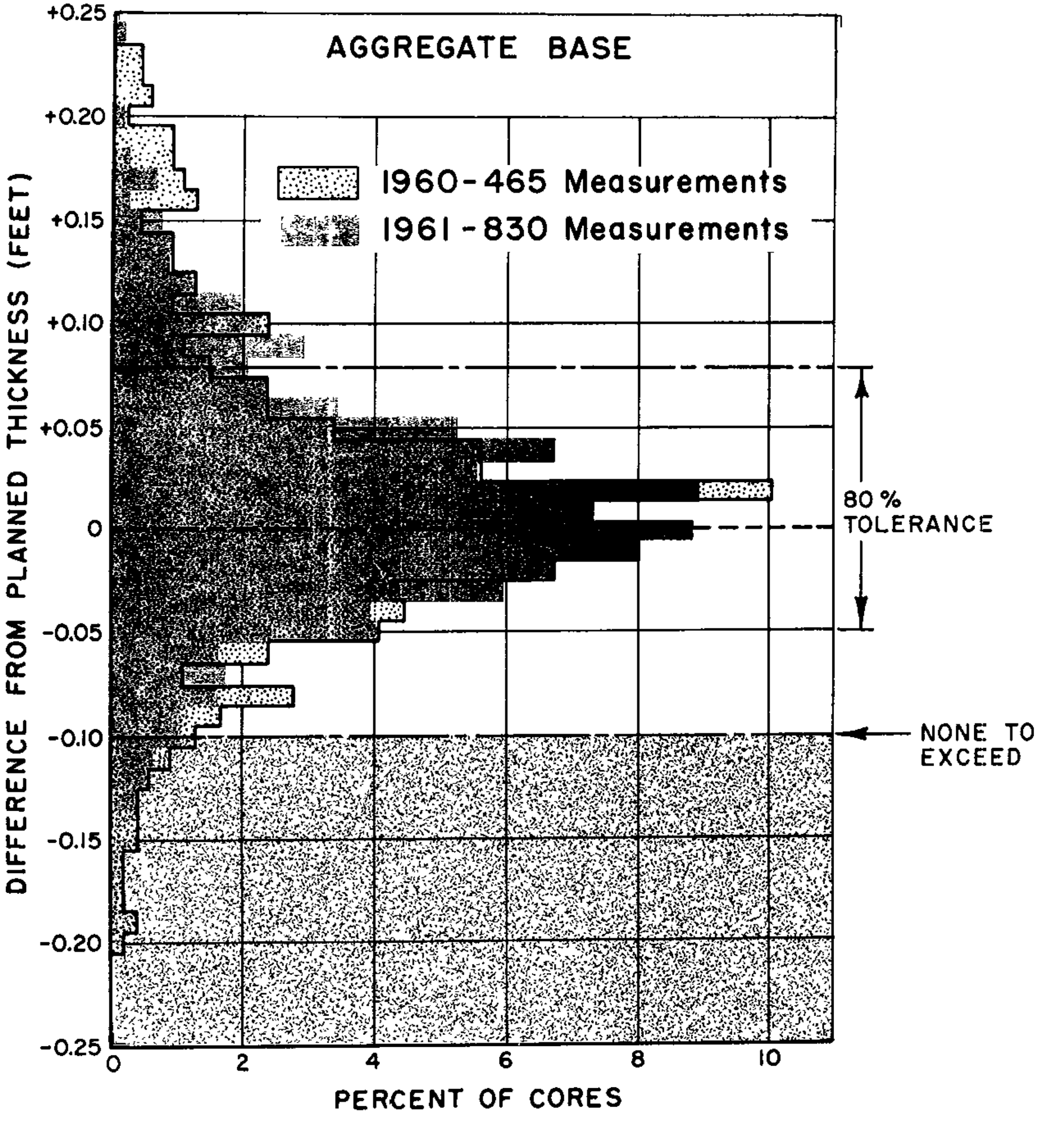


Figure 5

OGIVE CURVE FOR THICKNESS MEASUREMENTS OF AGGREGATE BASE

1960 and 1961 AUDIT SAMPLING PROGRAM

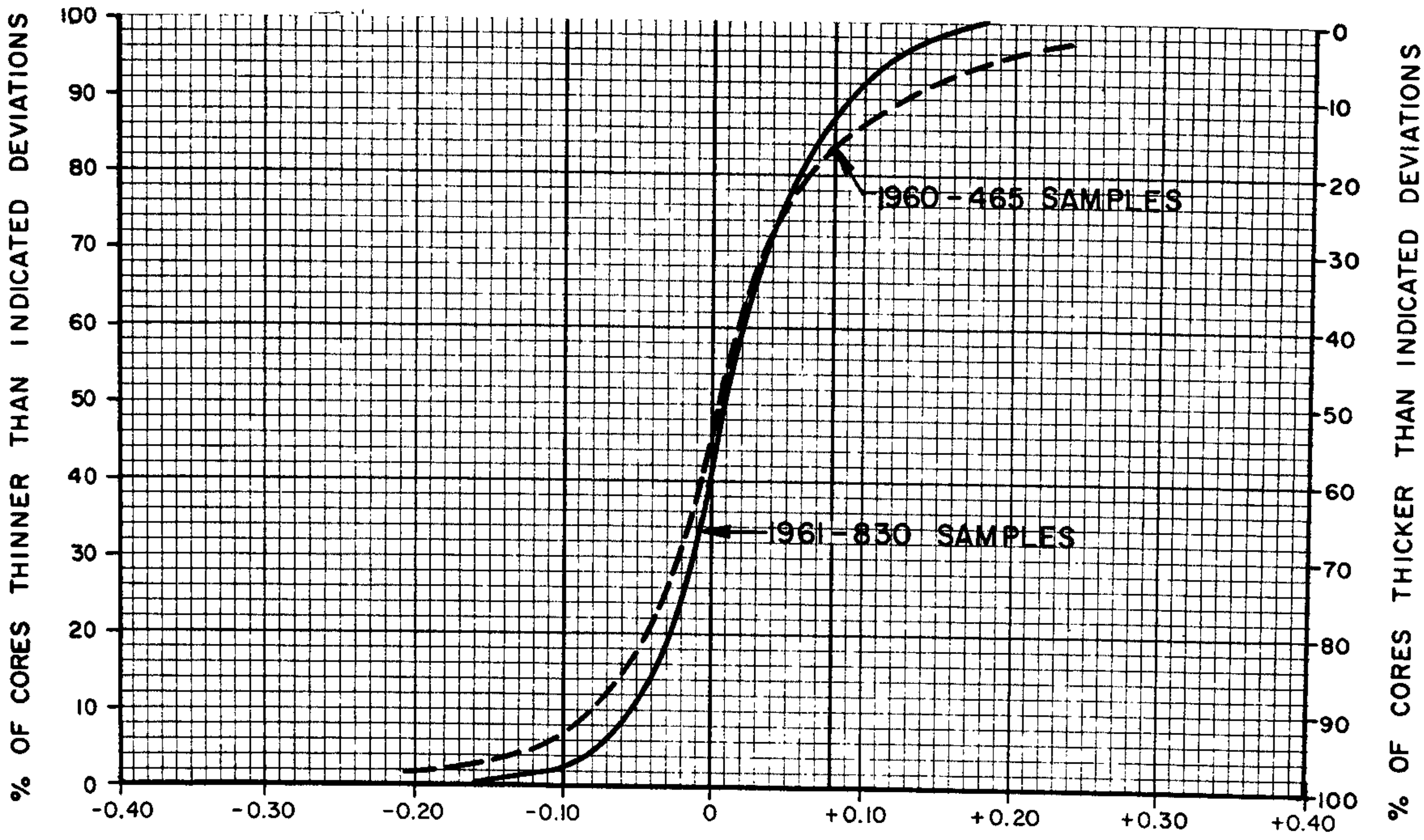


Figure 6

ENGINEERING AUDIT OF CONSTRUCTION

GRAPHICAL ILLUSTRATION OF VARIATION IN THICKNESS

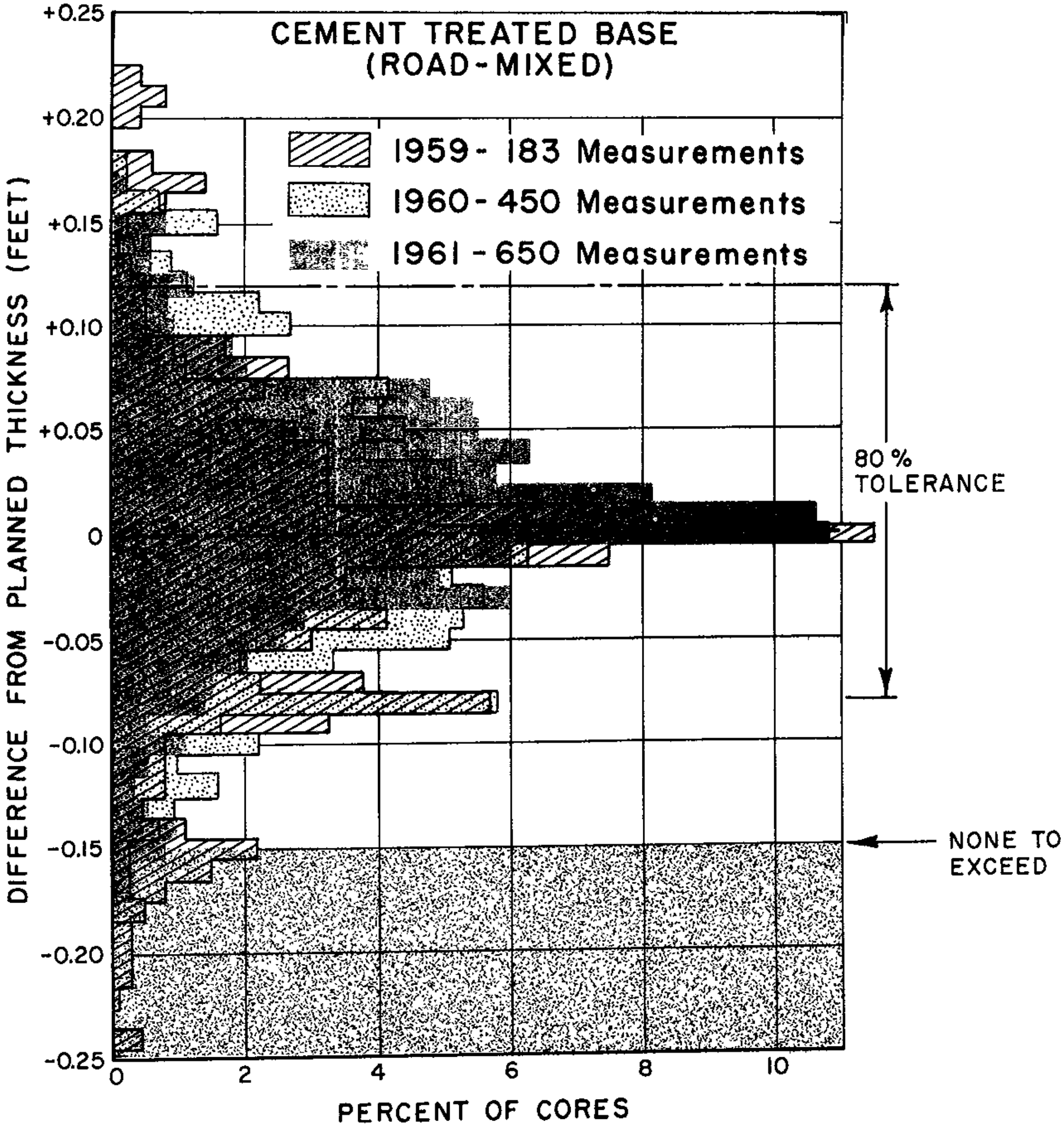


Figure 7

OGIVE CURVE FOR THICKNESS MEASUREMENTS OF ROAD - MIXED CEMENT TREATED BASE

1959, 1960 & 1961 AUDIT SAMPLING PROGRAM

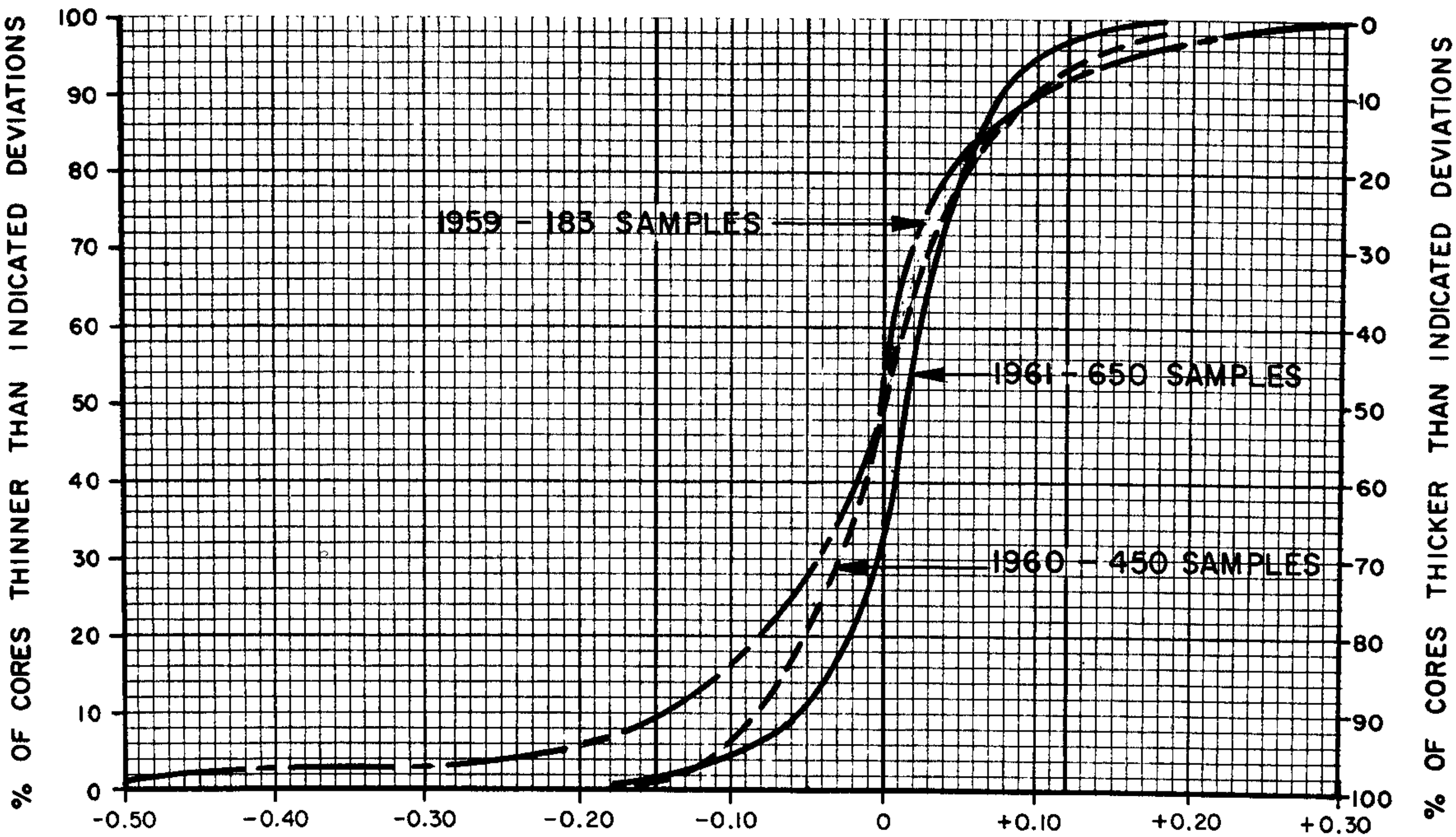


Figure 8

ENGINEERING AUDIT OF CONSTRUCTION

GRAPHICAL ILLUSTRATION OF VARIATION IN THICKNESS

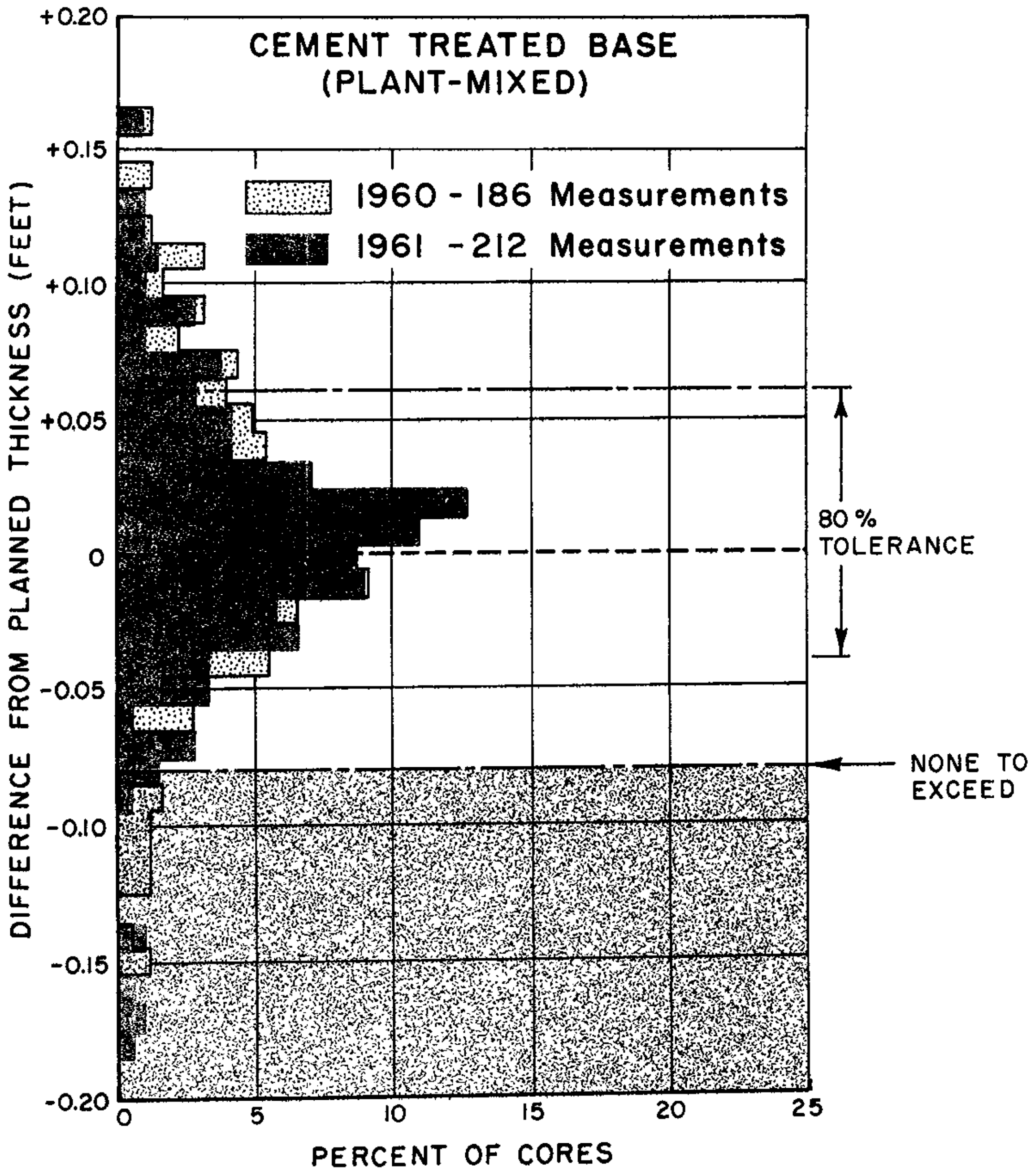


Figure 9

OGIVE CURVE FOR THICKNESS MEASUREMENTS OF PLANT-MIXED CEMENT TREATED BASE
1960 and 1961 AUDIT SAMPLING PROGRAM

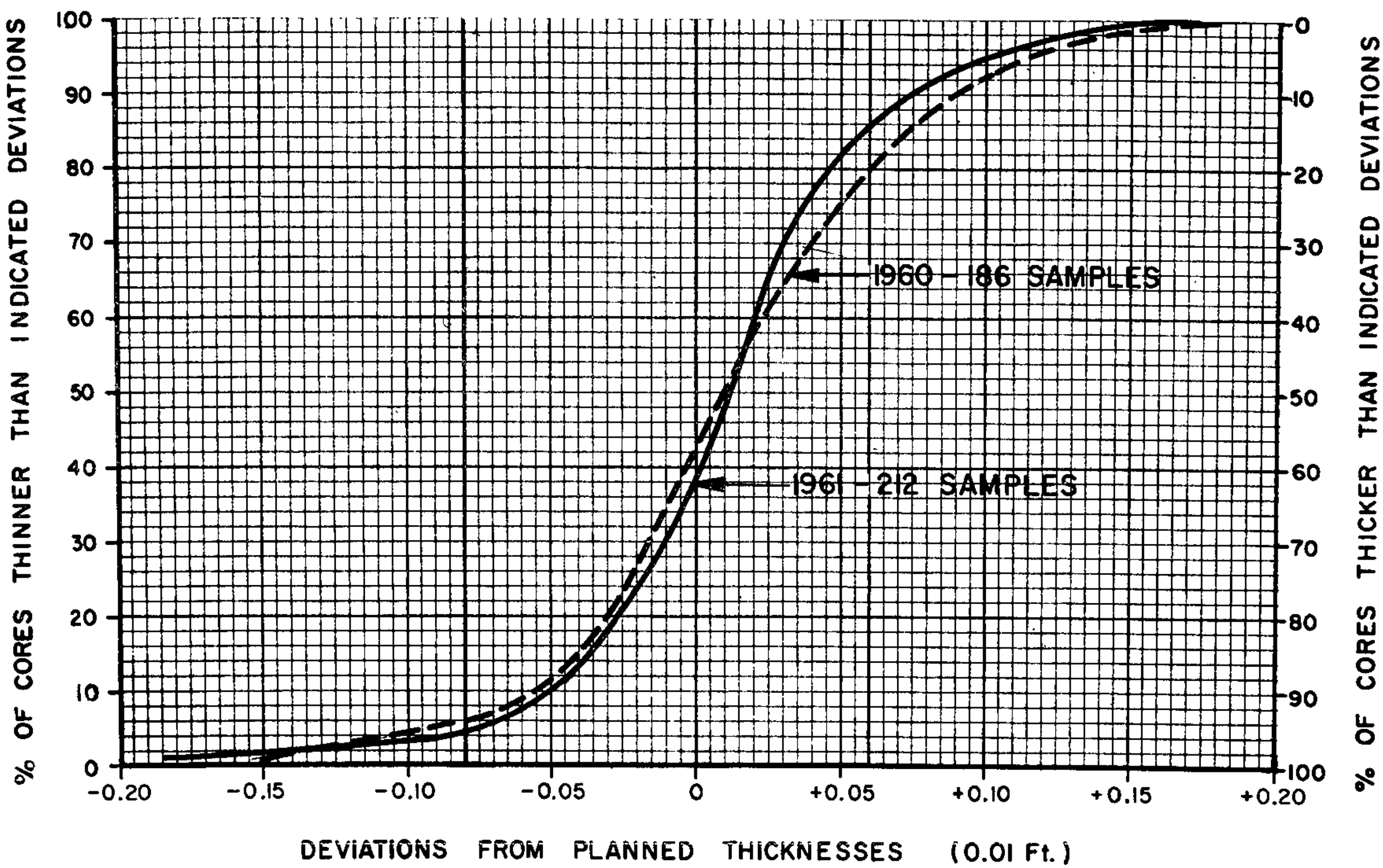


Figure 10

ENGINEERING AUDIT OF CONSTRUCTION

GRAPHICAL ILLUSTRATION OF VARIATION IN THICKNESS

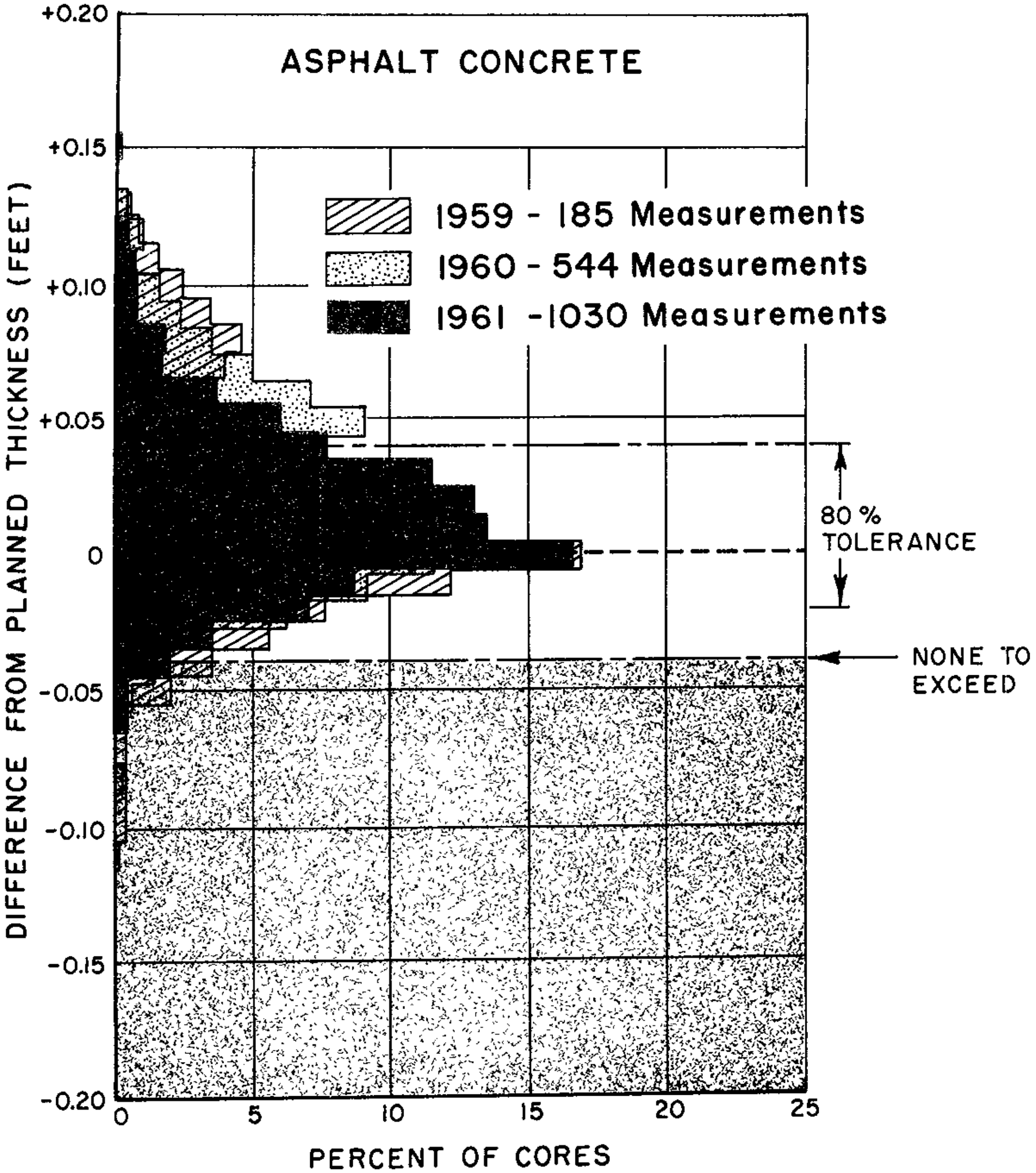


Figure 11

OGIVE CURVE FOR THICKNESS MEASUREMENTS OF ASPHALT CONCRETE

1959, 1960 & 1961 AUDIT SAMPLING PROGRAM

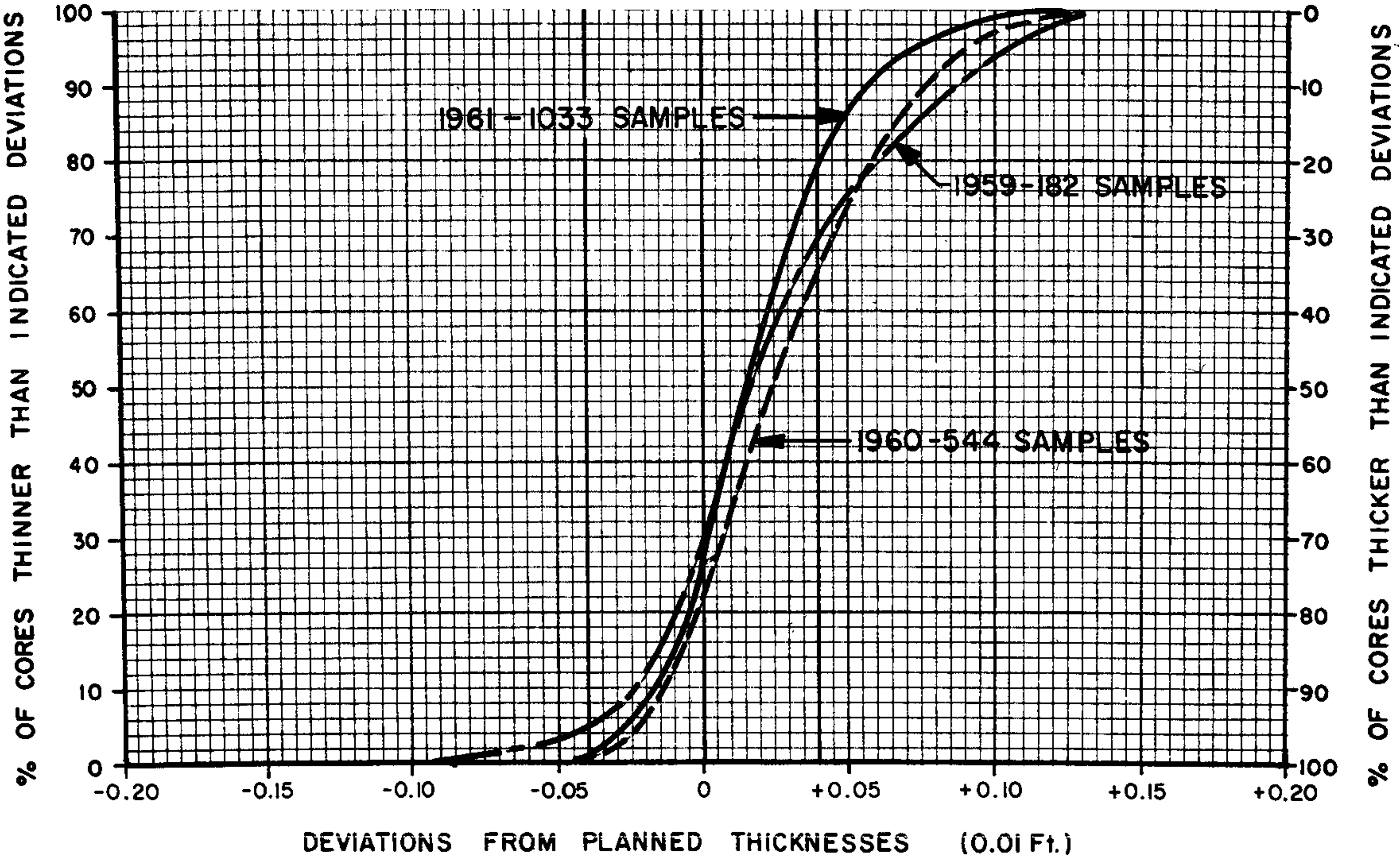


Figure 12

ENGINEERING AUDIT OF CONSTRUCTION

GRAPHICAL ILLUSTRATION OF VARIATION IN THICKNESS

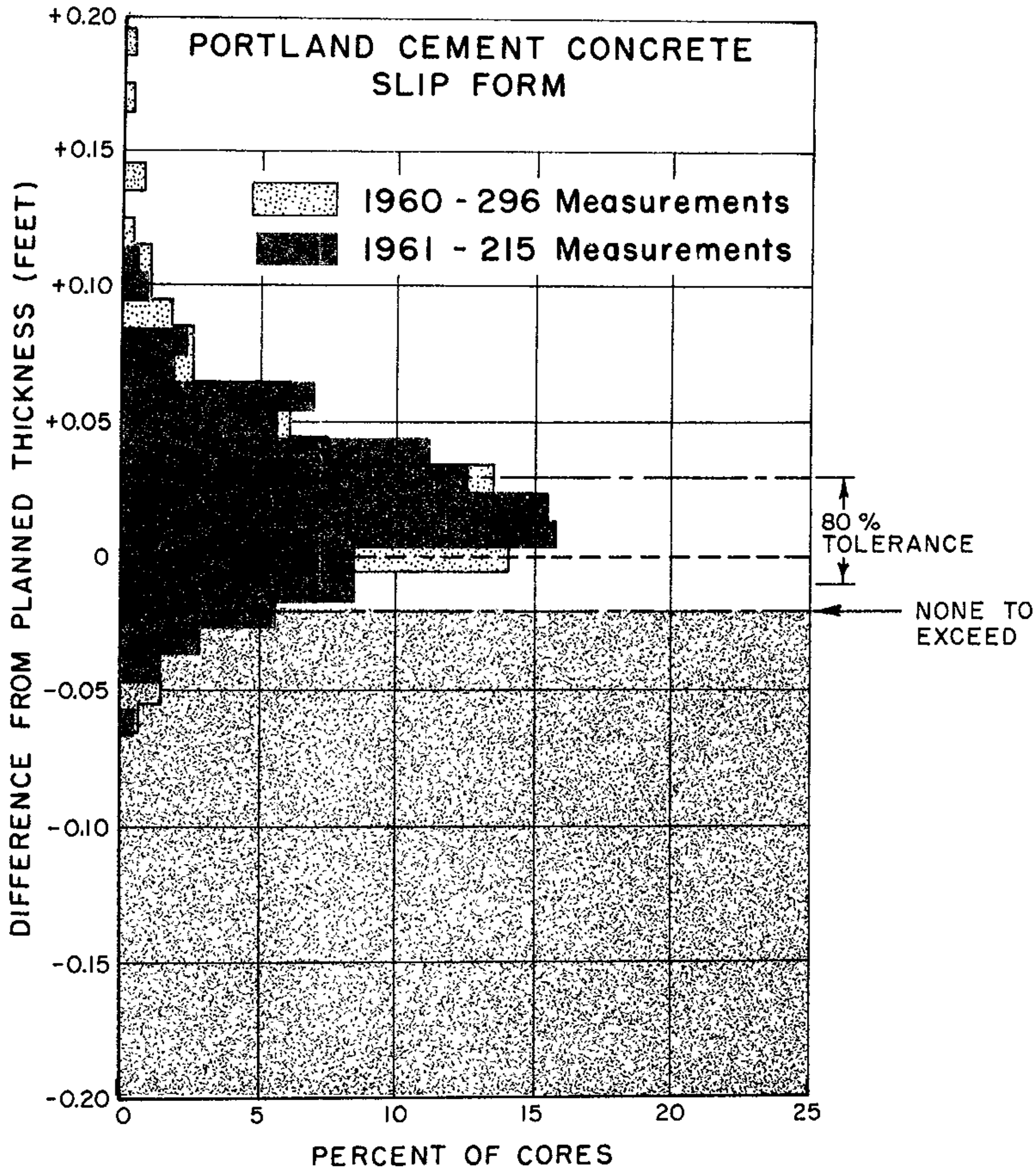


Figure 13

OGIVE CURVE FOR THICKNESS MEASUREMENTS OF PORTLAND CEMENT CONCRETE - SLIP FORM

1960 and 1961 AUDIT SAMPLING PROGRAM

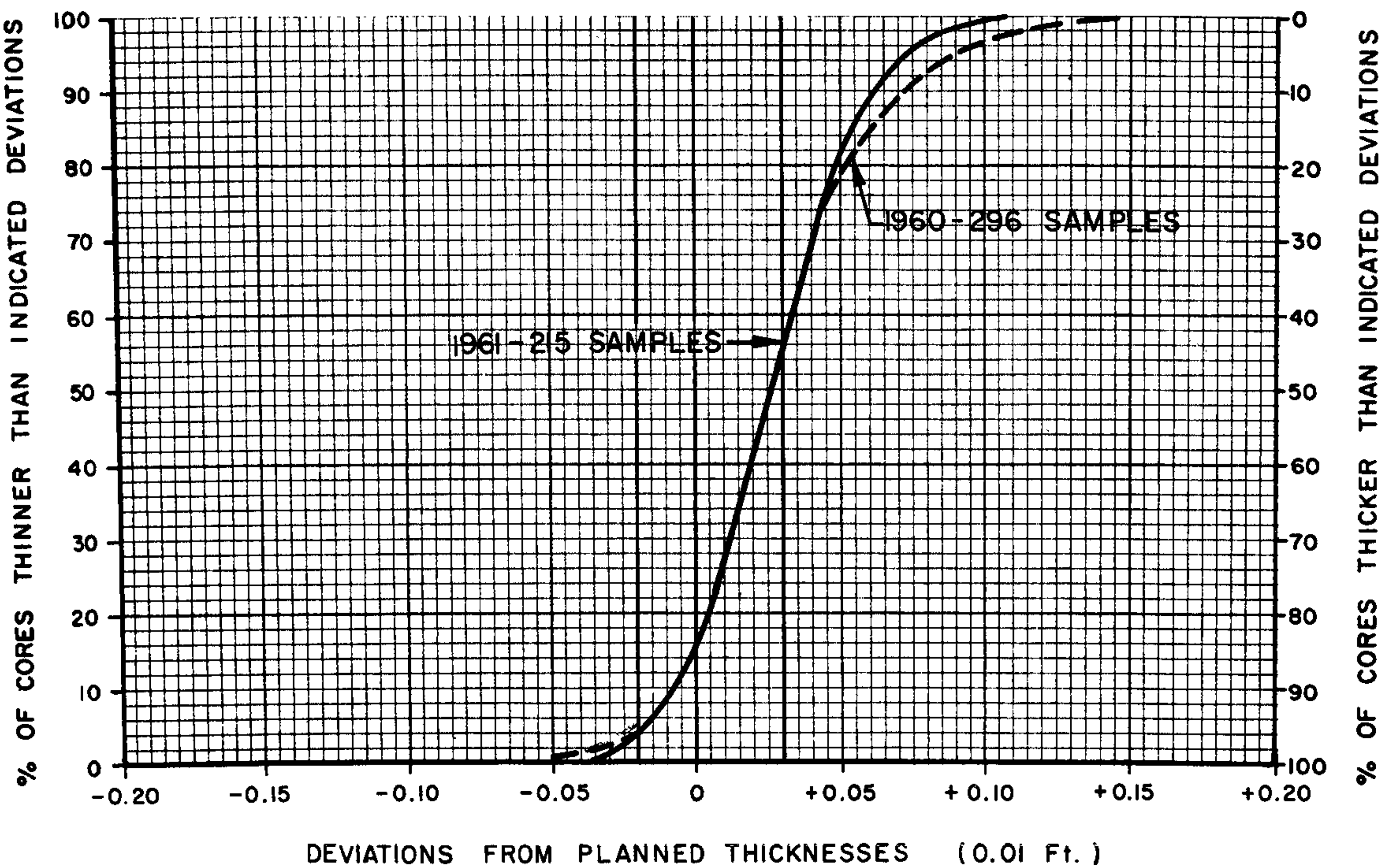


Figure 14

ENGINEERING AUDIT OF CONSTRUCTION

GRAPHICAL ILLUSTRATION OF VARIATION IN THICKNESS

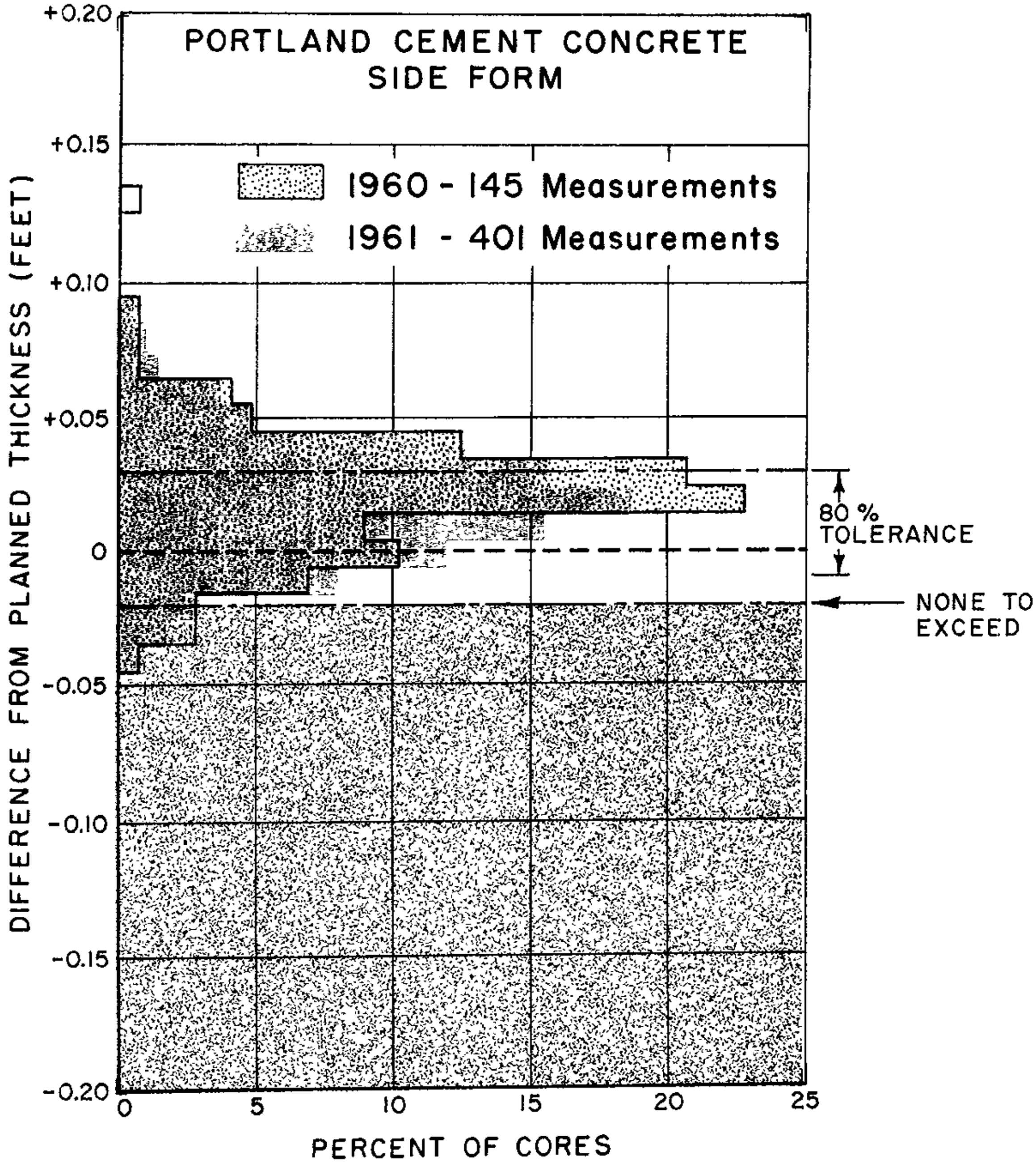


Figure 15

OGIVE CURVE FOR THICKNESS MEASUREMENTS OF PORTLAND CEMENT CONCRETE - SIDE FORM

1960 and 1961 AUDIT SAMPLING PROGRAM

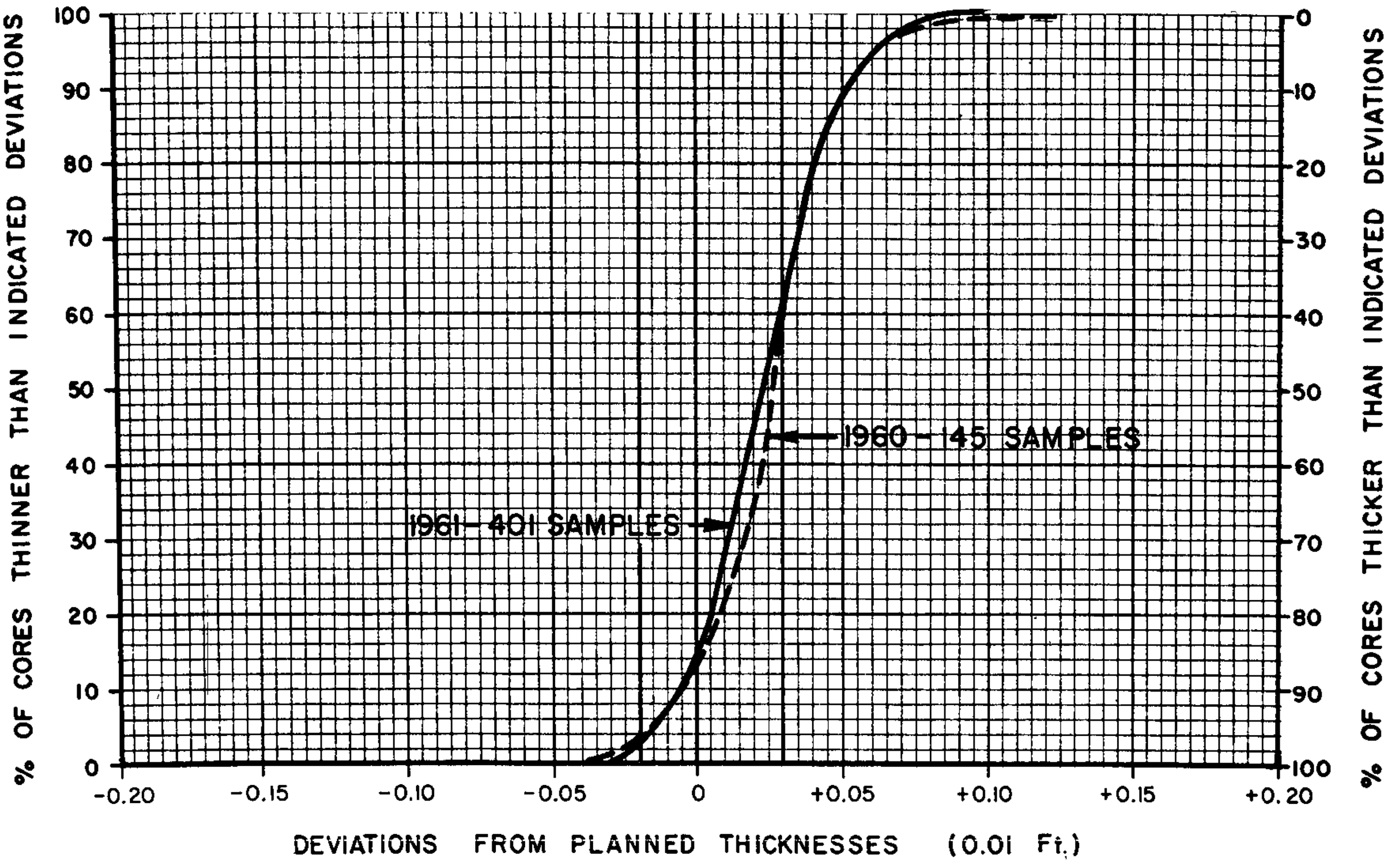


Figure 16

ENGINEERING AUDIT OF MATERIALS

GRAPHICAL ILLUSTRATION OF R-VALUE TEST VARIATION

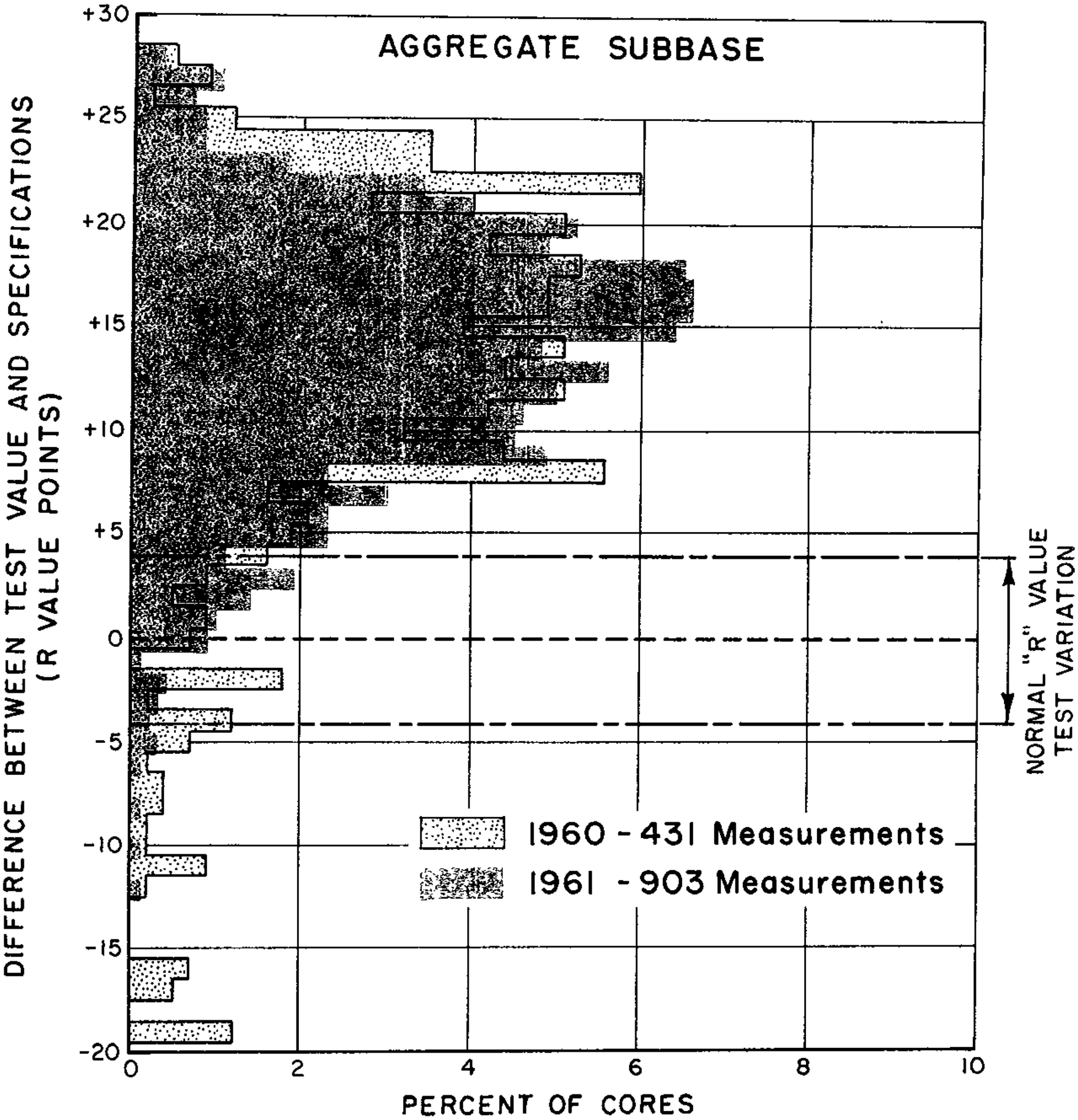


Figure 17

ENGINEERING AUDIT OF MATERIALS

GRAPHICAL ILLUSTRATION OF R-VALUE TEST VARIATION

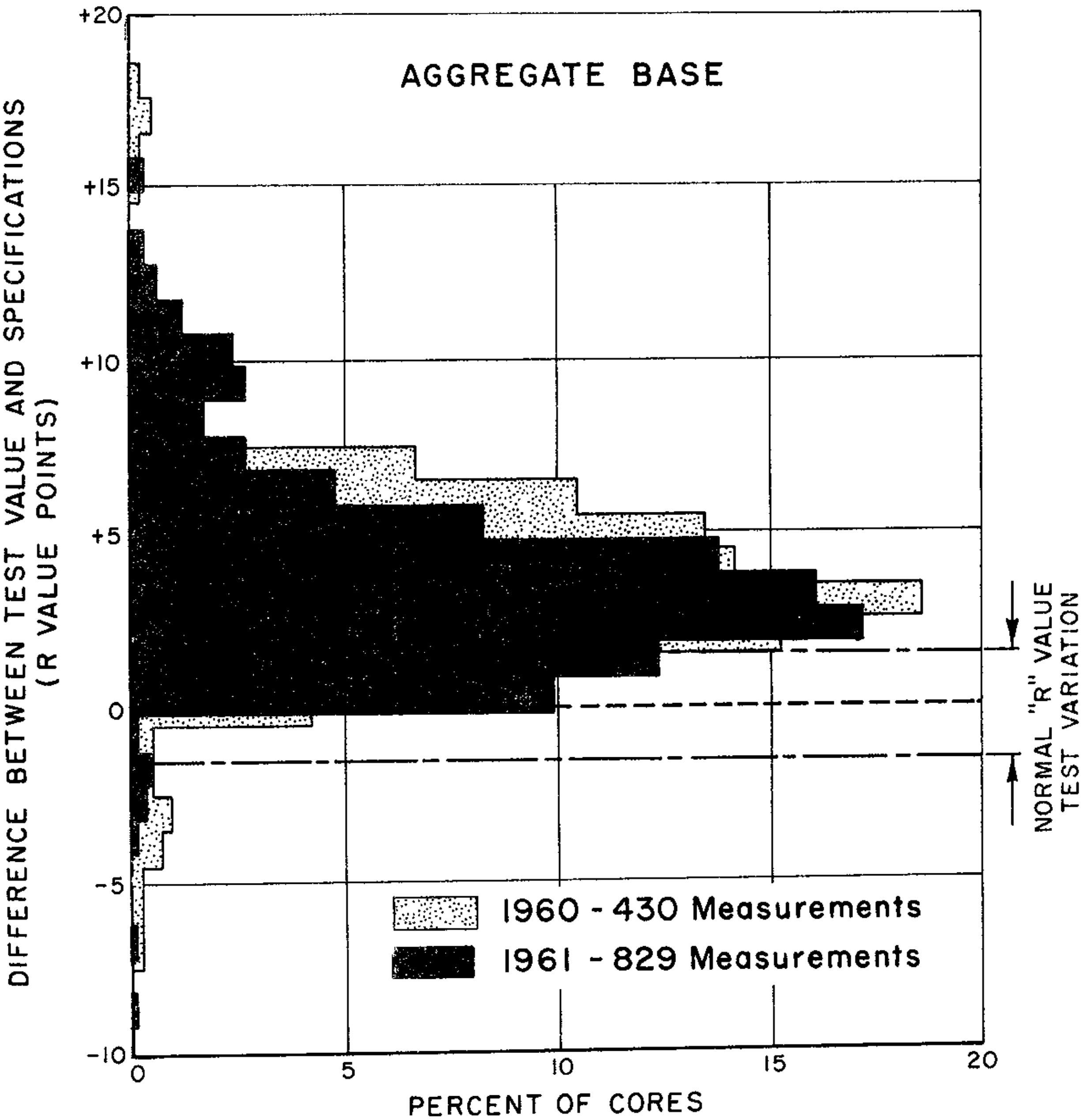


Figure 18

ENGINEERING AUDIT OF MATERIALS

GRAPHICAL ILLUSTRATION OF S.E. TEST VALUE VARIATION

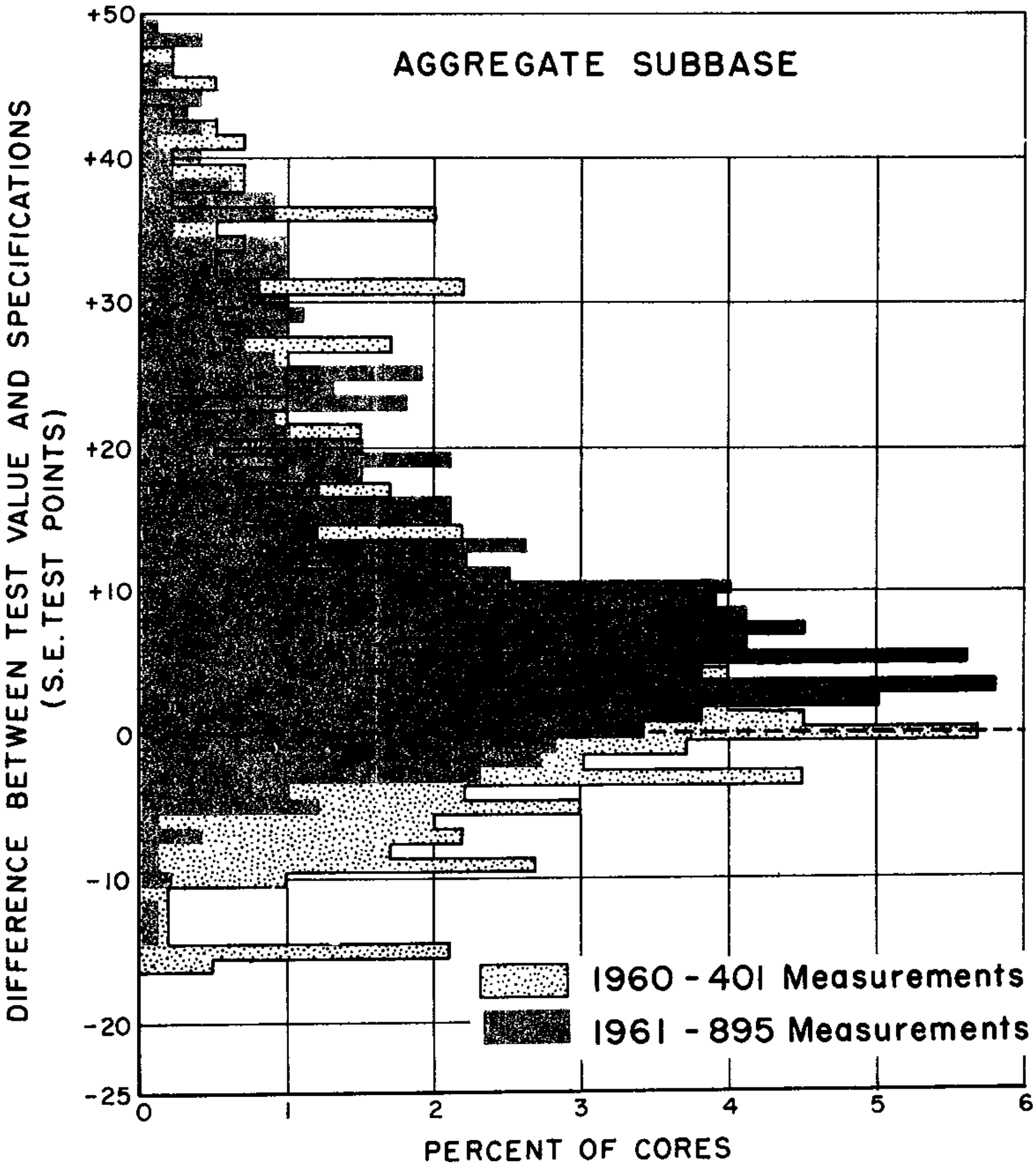


Figure 19

ENGINEERING AUDIT OF MATERIALS

GRAPHICAL ILLUSTRATION OF S. E. TEST VALUE VARIATION

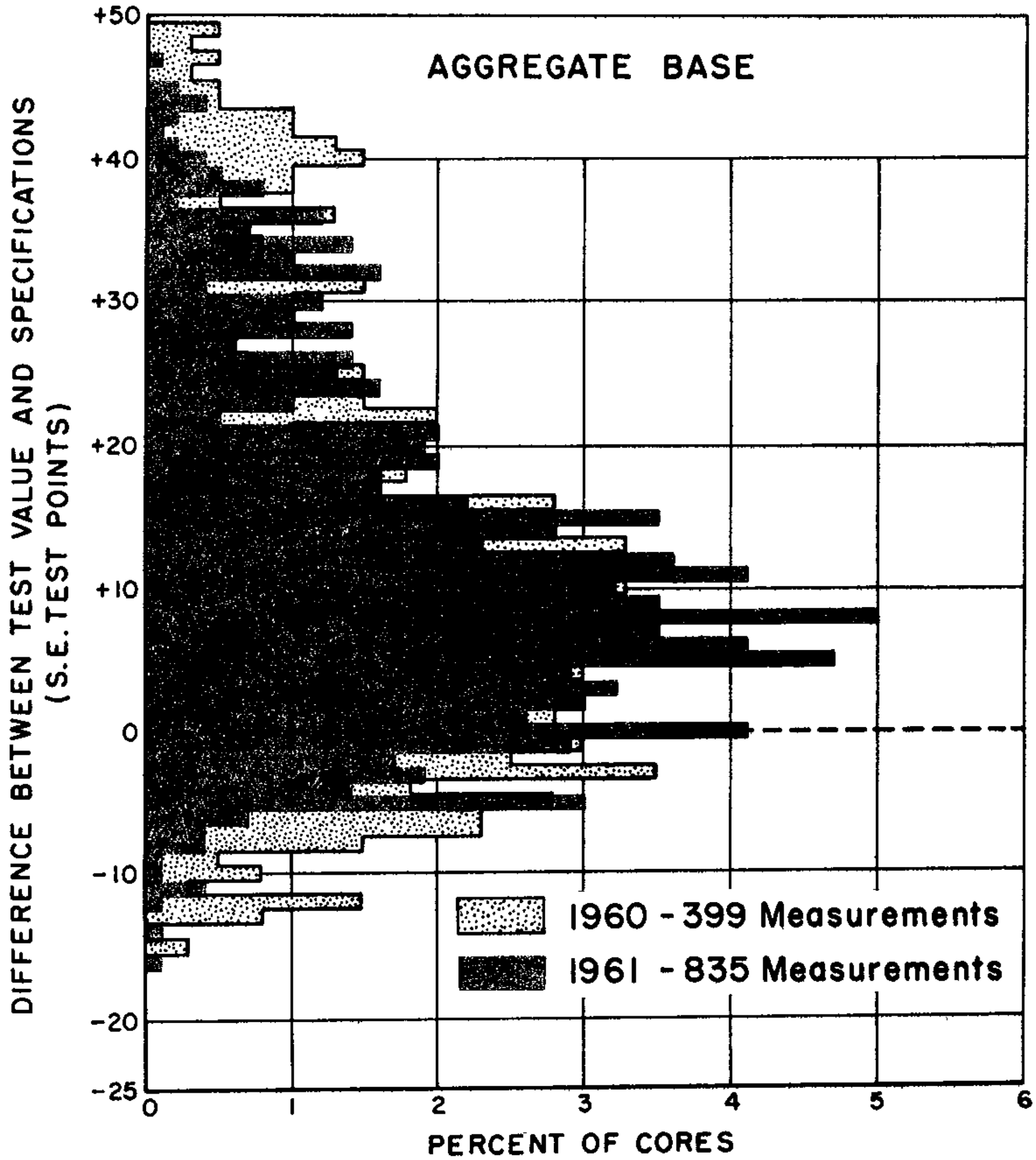


Figure 20

DISTRIBUTION OF COMPRESSIVE STRENGTH TESTS FOR FIVE INCH DIAMETER CORES OF PORTLAND CEMENT CONCRETE FOR JUNE 1, 1960 TO OCTOBER 1, 1961

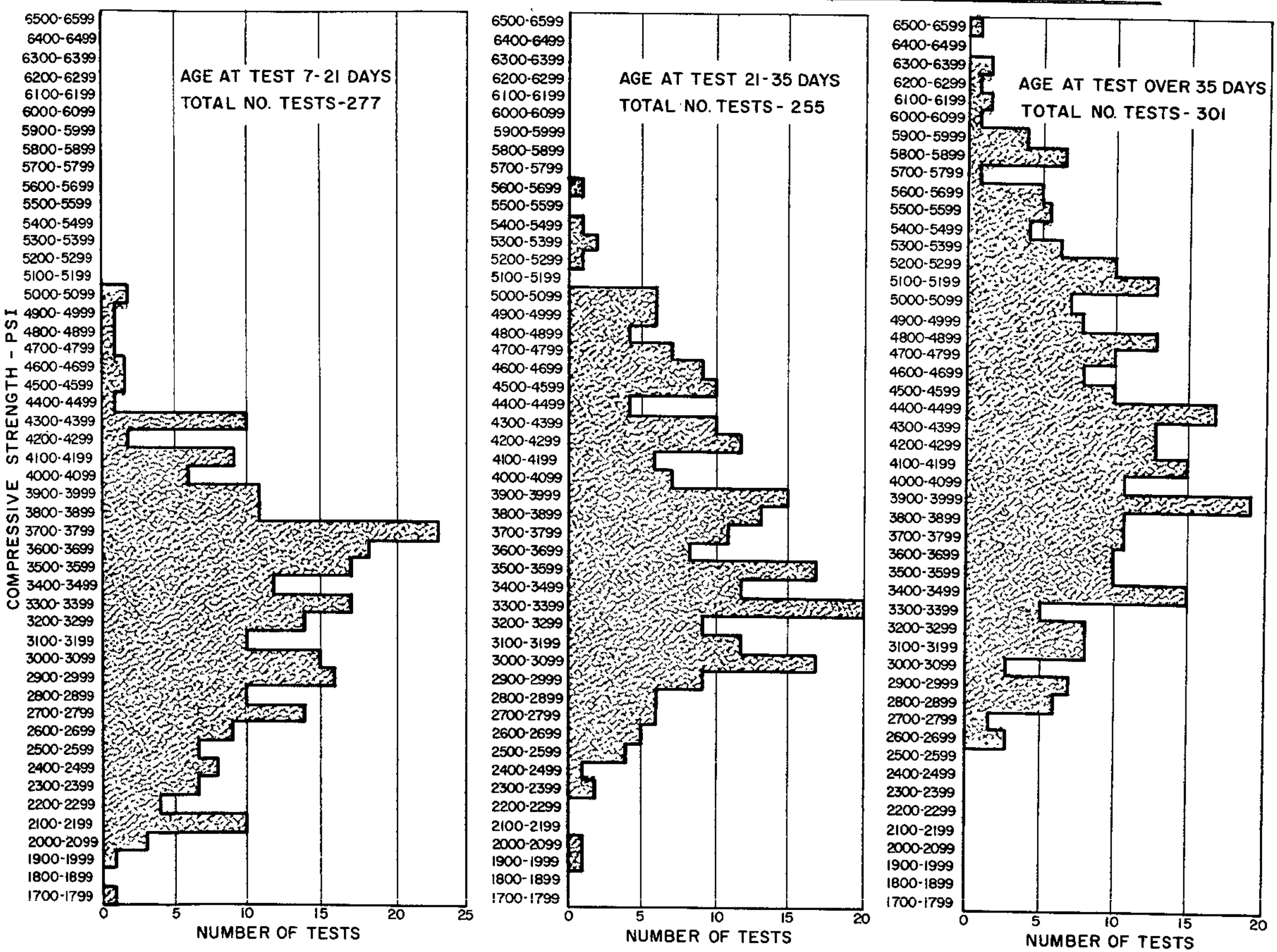


Figure 21

DISTRIBUTION OF COMPRESSIVE STRENGTH TESTS FOR FIVE INCH DIAMETER CORES OF PORTLAND CEMENT CONCRETE FOR JUNE 1, 1960 TO OCTOBER 1, 1961

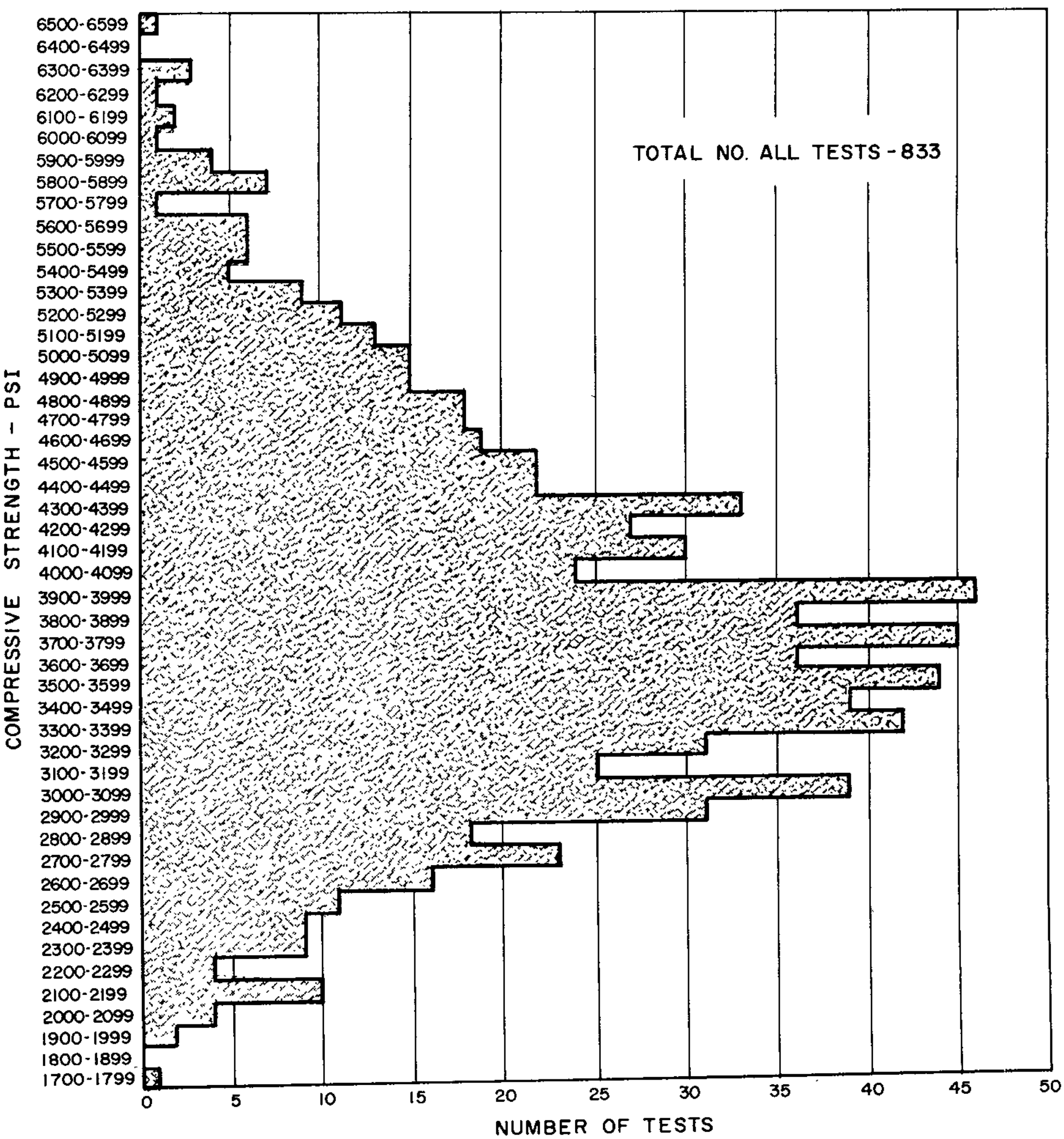


Figure 22

DISTRIBUTION OF COMPRESSIVE STRENGTH TESTS FOR 6"X12" CYLINDERS OF 6 SACK STRUCTURAL PORTLAND CEMENT CONCRETE FROM 15 CURRENT CONTRACTS SELECTED AT RANDOM IN THE STATE

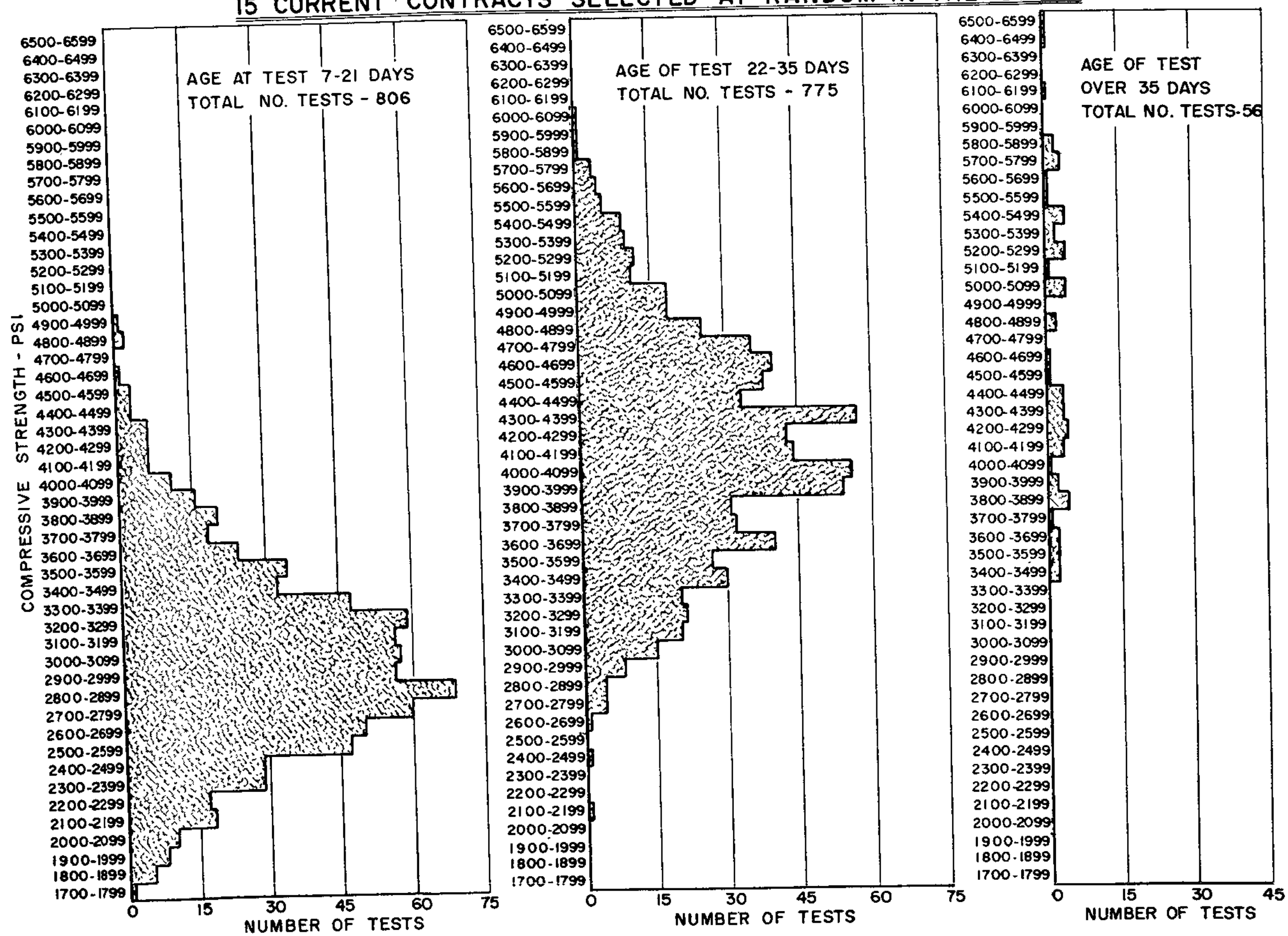


Figure 23

DISTRIBUTION OF COMPRESSIVE STRENGTH TESTS FOR 6" X 12" CYLINDERS OF 6 SACK STRUCTURAL PORTLAND CEMENT CONCRETE FROM 15 CURRENT CONTRACTS SELECTED AT RANDOM IN THE STATE

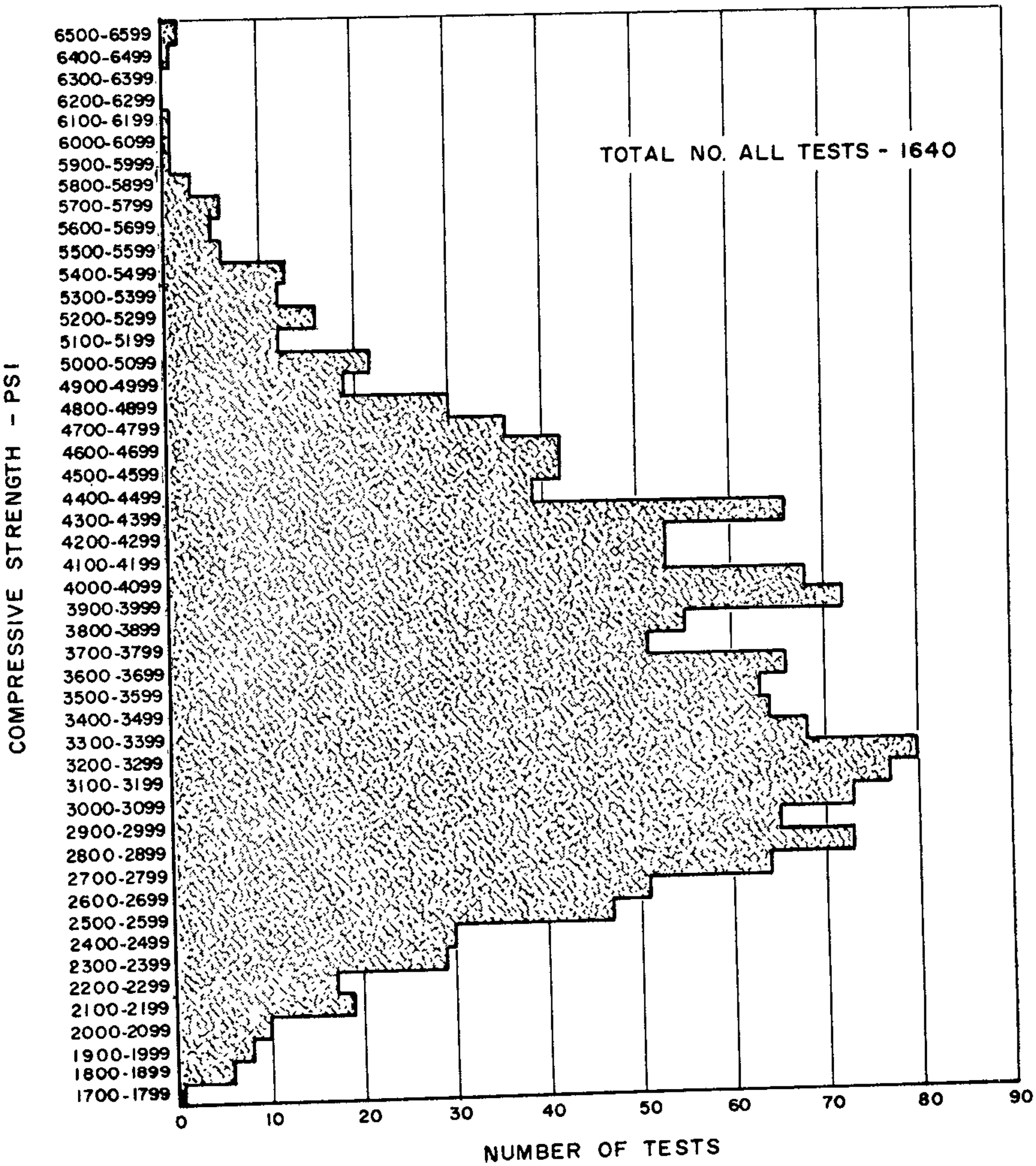


Figure 24

CHART SHOWING COMPARISON
BETWEEN LOSS AT 500 REVOLUTIONS IN L.A. RATTLER
AND DURABILITY VALUES ON COARSE AND FINE AGGREGATES

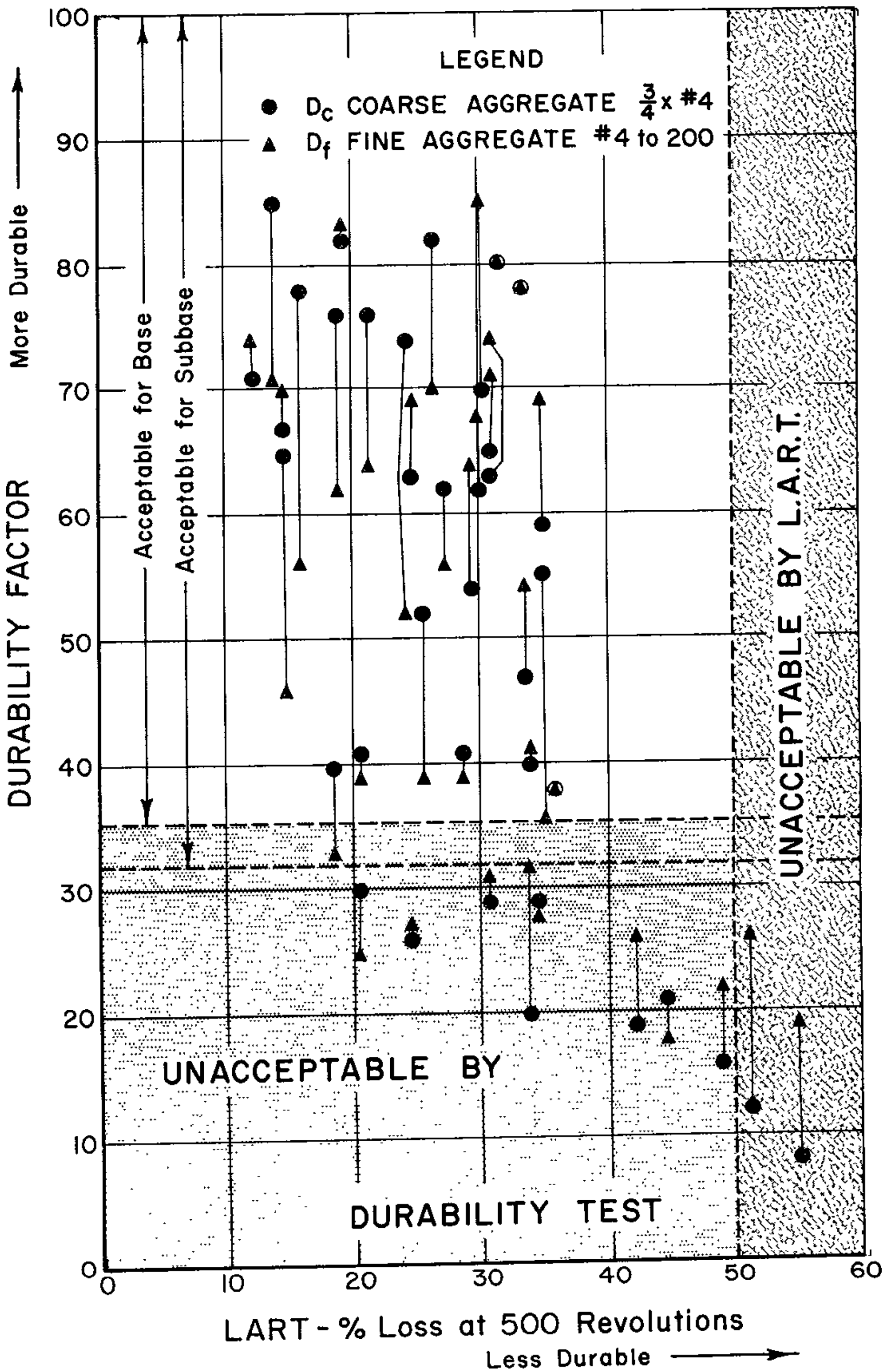


Figure 25